

The Traffic Design of Parking Garages

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A WELL-DESIGNED SHOPPER'S GARAGE

This garage has a capacity of about 1000 cars, with 3 levels of storage above the street and one below. Cars are parked in stalls 8 feet wide, from aisles 22 feet wide. A one-way tandem staggered floor ramp system is employed for the movement of cars, and a service elevator for the vertical movement of attendants (contained in the small penthouse in the foreground). The average time required to store or deliver a car is less than four minutes.

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AUTHOR'S PREFACE

The importance of off-street parking facilities is illustrated by the fact that surveys are being conducted in many towns and cities to determine deficiencies in the number of parking spaces. Plans are being made by municipal officials and private businessmen for new facilities. The conclusion common to most parking survey reports is that the problem cannot be solved at the curb and that additional off-street lots or garages are needed. Typical reports state:

Analysis and calculations derived from the findings of this survey show that there will be required . . . (in 1956) . . . a total of 26,676 parking spaces The present off-street parking facilities in the Triangle contain approximately 12,500 car spaces; . . . there are . . . only 845 legal curb spaces during off-peak periods. . . . The 32 recommended units include 20 new parking garages . . .¹

In 1944, there was need for 3000 additional spaces. This need is expected to increase to 6900 by 1950.²

Borough of Manhattan: We recommend the construction of 13 garages to accommodate 10,632 cars.³

It appears entirely logical to foresee 15,000 daily downtown parkings twenty years from now. Since the number of curb spaces will be steadily reduced off-street terminal expansion will need to be greatly accelerated if it is to keep pace with demand.⁴

This study was undertaken in the belief that many new parking garages will be opened within the next few years, and that the traffic aspects of garage design and operation warrant greater attention. The traffic design of such buildings is a relatively unexplored field, though in the structural design, architectural and engineering standards are highly developed.

The close inter-relationship of parking demands, the design of

¹*Parking Study of the Pittsburgh Central Business District*, Pittsburgh Regional Planning Association, 1946.

²*Detroit's Parking Needs—Central Business District*, City of Detroit Traffic Engineering Bureau, August, 1946.

³*Selected Measures for the Partial Relief of Traffic Congestion in New York City*, Gano Dunn et al, 1946.

⁴*Alexandria, Louisiana, Street and Highway Plan*, H. W. Lochner and Company, November, 1947.

facilities to meet these demands and the operation of such facilities are noted throughout the study. Appraisal of the parking demand is fundamental to the choice of design features, which in turn limit the methods of operation. Poor operation will adversely affect demand, so that potentialities of good design may not be realized. On the other hand, superior operation techniques may overcome deficiencies in design. A close appraisal of demand characteristics, of design features, or of operational methods must be based upon the effect of the other elements.

Owners and operators were helpful in allowing access to their facilities and in giving opinions on garage design. It seems wise not to identify operational data with specific garages. Contributors, therefore, remain anonymous.

The author acknowledges the useful suggestions and other assistance of members of the staff of the Bureau of Highway Traffic and of the Eno Foundation. Credit is due Theodore M. Matson, Director of the Bureau, for suggesting the idea of the study and for a technical review of the manuscript. Frederick W. Hurd assisted in collecting field data and in the theoretical treatment of design features. Special appreciation is due Francis E. Twiss for his major contribution in the preparation of illustrative material.

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New Haven, Connecticut
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CHAPTER I

INTRODUCTION

This study evaluates the design features of off-street parking facilities from the viewpoint of traffic engineering, and presents factual data for those interested in building new facilities, either as owners or designers. Methods and techniques that the traffic engineer applies to traffic on the highway and street system apply directly to location, design, and operation of terminal facilities.

The Significance of Operating Time

The usefulness and adequacy of off-street parking facilities often have been measured in terms of the gross number of cars accommodated. A more significant measure can be made in terms of *time*, whether measured in the actual time required to handle each car, or in the total time a patron must spend in getting parking service.

Some of the largest and most modern parking garages have peak outbound movements that require each customer to wait as much as twenty minutes for delivery; yet the parking and un-parking operation need total no more than two to five minutes for each car. This waste of time is important to the customer, who often withdraws his patronage. It is important to the garage operator because of lost business and the high cost of inefficient service.

Throughout this study, an attempt has been made to determine the key features of design and operation, and to evaluate them on the basis of time. It is often found that individual savings in time may be quite small, as in reducing the walking distance of attendants. Yet the total savings assume considerable importance, and can be the basis for significant improvements in parking efficiency.

Time-saving in parking does not mean that cars must be driven at high speeds or that attendants must run. Important savings

can be realized by the functional layout of physical features and by efficient and well-supervised operation.

Garage vs. Lots

Attention has been primarily centered on the design of *parking garages* rather than of *parking lots* because of the greater complexity and permanence of garages. Many lot and garage characteristics are similar, and studies of each may be interchangeable.

Parking lots may be quickly installed on vacant land parcels, or abandoned in favor of more intensive land use. The stall-size and arrangement can be varied without structural changes. The sites of successful lots are often found suitable for garages when additional capacity is needed.

The distinguishing features of garages are: (1) more parking stalls in a given area, (2) permanence, and (3) larger investment. These features accentuate the importance of good design, particularly in providing for a rapid handling of cars and in adaptability to future changes of car design.

METHOD OF STUDY

Much study and many reports have been concerned with the parking problem, but relatively little has been written on the design of new facilities. Certain accepted standards of stall and aisle dimensions, ceiling heights, and ramp slopes have grown up, and may be found in the publications of such organizations as the American Automobile Association¹ and the Portland Cement Association.²

In another and earlier period of intense garage-building activity, the 1920's, several architectural publications presented articles covering the standards and styles of that day. The most notable was published in the February 1929 issue of the *Architectural Record*.³ Although such articles are "dated" by the

¹*Parking Manual*. Traffic Engineering and Safety Department, American Automobile Association, 1946.

²*Concrete for Industrial Buildings and Garages*. Portland Cement Association, Chicago, Illinois, 1946.

³"Garages, Standards for Design and Construction". E. P. Goodrich, et al. *Architectural Record*, February 1929. Vol. LXV, p. 178.

changes in automobiles, they provide a basis for study of many existing garages built to those standards, and they point up variables that must be recognized in designing garages today.

Observations in Garages

Most of the information in this study came from actual observation and time-motion studies made in existing garages. The major operations, such as driving on ramps, backing into parking stalls, driving out of parking stalls, walking up and down stairs, issuing tickets were individually timed with a stop watch. Enough separate measurements were made to get a reliable average and to determine the significance of each operation in relation to others. Wherever distance or speed was important in these operations, lineal measurements were made, either in the garage or from the plans. A check of over-all operations was taken by recording the total time required by individual drivers to handle a car, and the waiting time of customers. Parking attendants were not individually compared: it was assumed that any group of present drivers would represent the *average* in any new garage.

Field trips were made to Boston, New York, Philadelphia, Baltimore, Washington, Detroit, and Cincinnati. Detailed time-motion studies were made in a dozen garages and operation and design were observed in twenty-five others. The appraisal and evaluation of design elements, impossible to measure directly, indicate the opinions of these men. Because of the confidential nature of the financial and operational data supplied, all identifying references to individual garages have been omitted.

At each garage where a major study was made, the parking tickets for the period of the study were analyzed as a background for determining parking demand and usage.

Movie Technique

Some vehicular movements were found too complex for one observer to measure without upsetting the routine of the garage. Among these was the movement of cars to un-park another car. Such movements can be duplicated in parking lots or con-

veniently measured with the movie camera technique developed by Dr. Bruce Greenshields, and described in "Traffic Performance at Urban Street Intersections."⁴ This method was found successful. It also checked values on simpler operations previously timed with a stop-watch.

Certain factors in vehicular movements such as turning radius and clearance were checked by actual measurements on typical cars. A questionnaire was sent to the principal automobile manufacturers concerning the critical dimensions of 1947 models. The limitations of time and facilities prevented some desirable measurements; as for instance, the experimental determination of optimum bank, curvature, and the slope of ramps.

SUMMARY

The design data presented in this report are based on observation, time-motion statistics, and theoretical considerations of parking demand and automobile dimensions. Although the design of any particular parking facility must reflect local conditions and values, the conclusions have wide application, and point up the importance of *time* in parking operations.

⁴*Traffic Performance at Urban Street Intersections*. Bruce D. Greenshields, *et al.* Technical Report No. 1. Bureau of Highway Traffic, Yale University, 1946. p. 1.

CHAPTER II

FUNDAMENTAL FACTORS OF A PARKING GARAGE

The average car-parker desires to store his car near his destination, to spend a minimum time parking and un-parking it, and be sure it is safe, all at a minimum cost to himself. His wishes might be satisfied by a curb-stall at the entrance of the building to which he is going; and he will give or withhold his patronage to a garage according to how closely it approaches this idea. The now almost defunct curb-stall did provide easy access to both buildings and traffic streams at little or no direct cost. These ideals should be considered basic in garage design.

Safe storage as near as practicable to the parker's destination, therefore, is a fundamental service demanded of a parking facility. The separate parking desires of all motorists together form a parking demand. Individual downtown buildings or areas, the destination of certain groups, have a specialized demand—department stores, market areas, office buildings, theaters, for instance. Each type of demand, moreover, has different characteristics of occurrence and duration. But for all types, the first quality to be assayed for the plans of a proposed parking area is sufficient nearness to destinations desired by a sufficient number of motorists.

Rapid Absorption and Delivery

Since a prime consideration in the use of motor vehicles is to save time, one of the many reasons the motorist brings his car downtown in the first place is the desire for convenient and rapid transportation. If motorists must drive inconvenient distances to a parking place, or spend undue time in placing their cars, the principal reason for driving in the city is lost. Customers therefore demand not only desirable location but a rapid absorption of cars. So does efficient operation.

Observation proves that the average motorist, impatient to dis-

pose of his car on arrival, is much more impatient to get it out again. Whatever his reasons for delay in arriving at the garage, he expects his car to be delivered as soon as he calls for it. Garages therefore must be able to deliver any parker's car in an acceptable minimum of time.

Reliable and Safe Operation

The motorist expects many things of a garage. In addition to simple storage, the motorist wishes his car and its contents to be safe from theft and fire, and from mechanical damage by mistreatment or collisions within the garage. This last factor alone may make or break the reputation of a garage, and hence determine its sufficient or insufficient patronage.

The ultimate measure an average motorist applies to parking facilities is the cost of storage. Also he compares it with the cost of the curb parking that is either "free" at the expense of the municipality or metered for a few pennies an hour. Although there is a small "carriage trade" demand for extra service in certain garages, the design and operation of most parking garages must be aimed at keeping the cost low enough to attract enough parkers.

ARRANGEMENT OF A TYPICAL GARAGE

A parking lot may be divided into three areas of use: (1) the open space near the entrance where cars are accepted and delivered; (2) parking stalls where cars are stored; and (3) the aisles to these stalls. Some parking garages have separate entrances for each floor level, and may be operated as a series of parking lots, one above the other. Most garages consist of a main floor and several storage floors, connected by ramps¹ for the interchange of cars. The main floor serves principally for acceptance and delivery; storage floors contain stalls and aisles.

Certain minimum administrative and bookkeeping procedures

¹Freight elevators are often used to move cars in garages. They are generally considered obsolescent, and were so found in this study. A description and discussion of freight elevators will be found in Chapter VI. Throughout the remainder of the text, the term "ramp" will be used exclusively to designate means of moving cars between different floor levels.

are necessary for successful operation, such as (1) the issuance of an identifying ticket-receipt for each car, (2) a system of locating cars, and (3) the collection of parking fees. Each of these items will be described briefly.

Main Floor

The main floor of a garage contains the entrances, exits, reservoir space, cashier's office, and other facilities, depending on the particular design. The entrance generally is located at street level, but in some cases is one story above or below ground. The reservoir space is an open area between the entrance and the ramp. There tickets are issued and passengers unloaded. This space serves the important function of absorbing peak flows of traffic that arrive at the garage at a higher rate than cars can be stored. Identification tickets are issued at the reservoir space. For this purpose a dispatch point with a time-clock is usually established. The cashier's office collects the fees. A small area, that may be called the outbound reservoir space, is set aside for the delivery of cars to waiting customers. These features are common to a parking lot, and must be duplicated for each floor of a garage that has separate entrances for each parking level.

In addition, a rather large area of all floors is occupied by the ramp system, and a smaller one by the manlift, stairs, or other interfloor driver-travel means. Other facilities on the main floor are manager's office, service and repair facilities, rest rooms, waiting room, check room, and sales rooms. The extent of such features varies widely among different garages.

Storage Floors

The storage floors are large open areas containing as many parking stalls as practicable, with access-aisles. Each stall usually is marked by paint lines, a low dividing island, or by its location between supporting columns.

Stalls are arranged on either side of a parking aisle, usually at right angles to it. In most cases, a single row of cars is parked along each side of the aisle, so that all cars are directly accessible

for movement. Many garages, however, are designed with part of the stalls arranged in double rows in order to make maximum use of space.

In addition, storage floors may contain service and repair facilities, washrooms for attendants, or any of the features listed as normally being placed on the main floor. Such facilities are less easily available than on the main floor, but the value of space is much less.

The ramps in a parking garage are sloping surfaces connecting all floors for driving cars between the main floor and storage floors. The geometric design varies greatly.

METHODS OF OPERATION

A significant difference in the operation of parking facilities is the extent to which a patron is expected to handle his own car. In an *attendant-parking* garage, the customer drives into and out of the reservoir space, but garage employees drive his car to and from the storage floors, and park and un-park it. In a *customer-parking garage*, the customer handles his own car entirely, guided and directed by garage employees as necessary. Combinations of these methods are also found, as when *monthly* customers are allowed to park their own cars in otherwise attendant-parking garages.

To illustrate the functions of various design features, the steps in operation of attendant-parking and customer-parking garages are described in the following paragraphs under the main headings *acceptance*, *storage*, and *delivery*. The operations described closely follow those in garages studied; they may be considered typical of modern and efficiently-operated garages.

ATTENDANT-PARKING

As the motorist drives into the garage, he passes into the reservoir space on the main floor. He leaves his car, receives a parking check, indicating the receipt of his car, and leaves.

One or more of the employees of the garage, who may be called floor-men, are in charge of the operations in the reservoir space,

directing the movement of incoming cars and issuing tickets. Several methods of ticketing will be described in Chapter IX, but the essential parts are:

1. A section which is given to the customer as a receipt.
2. A section with a large identification number that is placed on the car.
3. A section on which the location of the car is marked is filed in the cashier's cage until the customer returns.

Both the customer's check and the cashier's section are time-stamped by the floor-man as a means of computing the charge. As soon as an attendant² is available, he drives the first car in line in the reservoir space to a storage floor and parks it. Only garage employees are allowed on the storage floors. Cars are not locked; keys are not removed.

When the customer returns for his car, he presents his parking check to the cashier. The cashier selects the corresponding section, time-stamps it, and collects a fee corresponding to the rate schedule for the period shown on the ticket.

The cashier then places a part of the ticket in a rack to show attendants that the car is wanted. Attendants take tickets from the rack in rotation. During peak periods when cars are both entering and leaving the garage, the attendants drive one car to the parking floors and deliver another, thus reducing the time per car handled.

Summary

In an attendant-parking garage, the motorist is not concerned with the movements of his car except to drive it into and out of the garage. He seldom sees more than the cashier's office, waiting room and reservoir space.

Attendants move cars between the main floor and the storage floors, park and un-park them. The efficiency of garage operation is, to an important degree, determined by the rate at which the average attendant can park or deliver cars.

The principal advantages of attendant-parking are that the

²Throughout this report, the term "attendant" will be used to designate the employees who actually drive the cars within the garage.

customer is not involved in the time-consuming process, and that a few experienced men can place cars skillfully, using the minimum space per car. The payroll expense for attendants is justified by the larger number of cars they can park in a given area, compared to customer-parking. A disadvantage is that in busy periods, the attendants may not be able to deliver the cars as fast as customers call for them.

CUSTOMER-PARKING

As the customer drives into the garage, he must pause on the main floor only long enough to be issued an identification ticket and be told on what floor he is to park. In some garages, tickets are issued on the storage floors. A sign near the entrance directs customers to the proper level, requiring no stops on the main floor. On the storage floor, a garage employee is stationed to guide the customer in parking his car. This is necessary because most motorists are not accustomed to driving or backing in restricted space. Once in the stall, the customer may lock his car and leave.

In these customer-parking garages, cars are parked in single rows if they are to be locked. Exceptions are made in peak periods when surplus cars are stored in the aisles on an attendant-parking basis.

Cashier and identification operations in a customer-parking garage must be strict in order to avoid theft, since the public has access to storage floors. Customers pay at the cashier's desk and get receipts to turn over to the door man as they drive out. But they are free to deposit bundles in their cars and finally drive away.

Summary

In a customer-parking garage, the motorist is responsible for driving his car up and down ramps and for parking and un-parking it. Attendants are few, since they need only guide the motorists.

Principal advantages of a customer-parking garage are the saving in attendant wages and the customer's satisfaction in handling

his own car and locking it. Despite many drivers' inexperience in restricted-area parking, it has proved feasible in some garages to require customers to drive to the storage floors and do their own parking. Some motorists, however, will not do this.

COMBINED ATTENDANT- AND CUSTOMER-PARKING

In some garages, customers drive up and down the ramps, but attendants park and un-park. The system has several advantages: Customers are relieved of the difficulties of parking, and space-saving features of attendant-parking are gained; the time lost by attendants' driving on the ramps and returning for other cars is saved; the transfer from customer to attendant and from attendant to customer takes place on all floors, thus reducing the reservoir space required on the main floor. Cashier and identification operations are handled as in customer-parking garages.

CHAPTER III

TRAFFIC CONSIDERATIONS

Traffic considerations in parking garages may largely be thought of as extensions of street traffic considerations. This is logical, since garages or other parking facilities represent the destination or origin of almost all urban traffic movements. Parking demand and vehicle and driver movements within the garage may be analyzed, and the design and operation planned accordingly.

Parking demand may be evaluated as to quantity, as to time distribution of inbound and outbound movements, as to duration of storage and type of parker. Vehicle and driver movements may be analyzed either by the time required or by the distance moved and the space occupied.

PARKING DEMAND

The most difficult aspect of the problem to evaluate is the parking demand of the public as to location, amount, and intensity of use. Various approaches are currently being made by research organizations and governmental agencies. The most obvious way to determine parking demand is to analyze parkers' present habits through a parking survey.¹ The scope and techniques of such surveys, greatly improved recently in scope and technique, are widely used. Results to be expected from factual surveys include: evaluation of the average walking distance, the destinations of parkers, the rate of incoming and out-going movements, and a measurement of the quantity of additional facilities needed.

Although current parking surveys measure current parking habits, a more thorough-going psychological and statistical analysis is required to evaluate the effect of new facilities, as to location, parking fees, type of parking. Approaches to such studies have been made on the basis of house-to-house canvasses, questionnaires distributed to parkers, and other public-opinion

¹*Manual of Instructions for a Parking Study*, Public Roads Administration, Federal Works Agency, 1947, is available as a handbook.

sampling techniques. To date, no complete and reliable method has been developed for accurately determining the public's parking desires. Yet it is recognized that such analyses of the probable future parking demand should be the basis for proposed solutions.

While measurement of parking demand was not part of this study, certain data from time-stamped parking tickets and other garage records, are indicative of the habits and desires of the people now parking in garages. Measurements can thus be made of rates of inbound and outbound movements, times of peak movements, duration of parking, comparisons among days of the week and among months of the year, and other pertinent breakdowns.

The charts of parking activity shown in this chapter are not presented as being conclusive. They form a background for some of the studies made in other chapters. An extension of such analyses for a particular city or garage will reveal the traffic characteristics, provide a sound basis for the operation of existing facilities, and aid in evaluating the need for new facilities. A compilation of more extensive records will give a good understanding of the effect of weather, parking fees, adjacent business and social activity—in short, what makes parkers use a garage and how to obtain greater utilization of, and income from, parking space.

Seasonal Variation

The first aspect of the parking demand to consider is the variation throughout the year. In a given location, the same pattern will probably repeat itself year after year, except as it reflects major social and economic changes; gasoline rationing in wartime, for instance.

The seasonal pattern in most lots and garages has its peak during pre-Christmas shopping. The rest of the annual cycle goes from a low point during the winter months to a secondary peak in the late spring and another low point during the summer. The "annual average" line is crossed in March, June, September, and at the end of the year. Illustrative seasonal variation by

months are shown in Figure 1, based on the records of three garages which principally serve shoppers.³

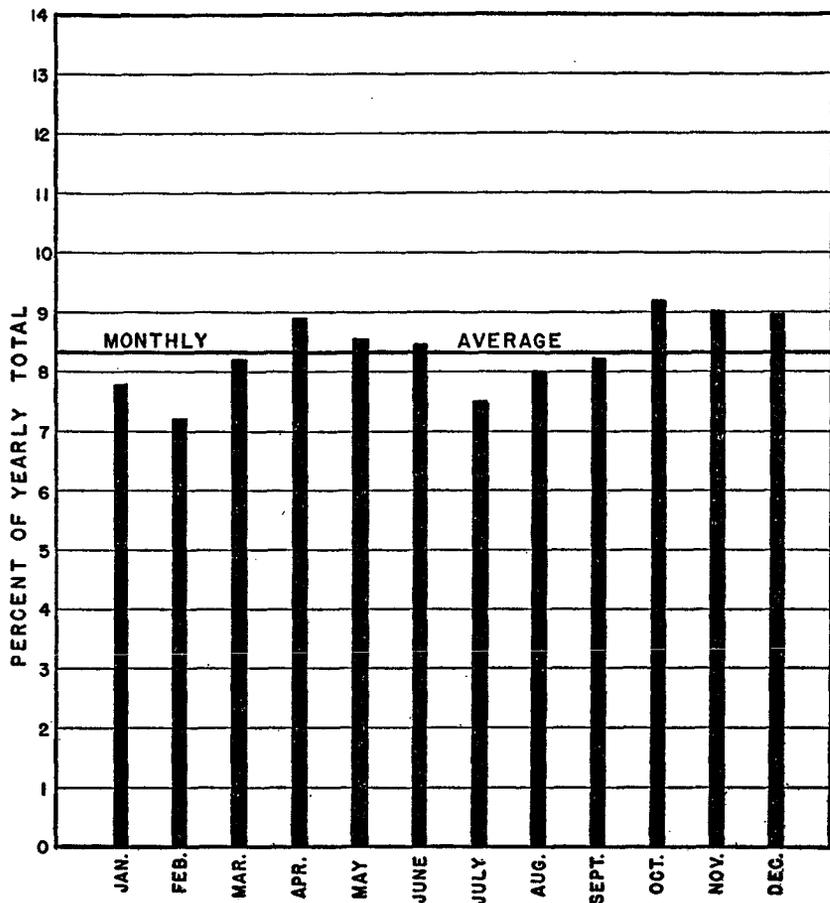


FIGURE 1. Seasonal Variation in Parking Activity

Variations from this pattern may depend on climate, type of patronage and local social habits. In northern cities, parkers sometimes move from lots into garages during the winter months, particularly if the garages are enclosed and heated. Rain and snow storms produce a similar effect, but not enough to change

³Data adapted from student thesis *Parking Characteristics of Department Store Garages*, Edwin C. M. Lee, Bureau of Highway Traffic, Yale University, 1947.

the seasonal pattern. The summer low will vary among cities, reflecting the extent of vacations of regular customers and the influx of tourists. Operators of some garages say their long-term patronage is affected by religious holidays, store hours, and other social patterns. The seasonal parking demand does not follow the pattern of road traffic except in a general way; it is more indicative of shopping, social and other metropolitan activities.

Study of the seasonal variations in parking demand in a particular city or parking facility will help to determine the number of attendants required at different seasons and in the interpretation of parking data collected over a short period.

Daily Variation

Within the long-term seasonal pattern of parking demand, there is a shorter and more accentuated cycle characterized by the demand on different days of the week. Within short periods of the seasonal cycle, this daily variation may be expected to repeat itself from week to week.

The weekly cycle follows a general pattern of low Sundays, high Saturdays, and a rather uniform level on weekdays. Individual garages are highly sensitive to local activities, such as shopping nights, which change the normal pattern of days. The weekly pattern of a large customer-parking garage, averaged over a period of three months,^a is shown in Figure 2. The values given for each day are the percentage of total weekly transient parkers, expressed as an average for the period studied. This garage serves a variety of patrons: theatregoers, shoppers, office workers, and hotel guests.

The weekly parking pattern may be applied directly in estimating probable revenues and the necessary capacity for new facilities, and it may be used also to determine the working schedules of employees. Garages used chiefly by business parkers may not have enough patronage to justify operation on Saturdays and Sundays, and the anticipated revenues of garages in commercial areas must be computed on the basis of a five-day week.

^aOctober and November, 1946, March 1947.

Shoppers' garages connected with department stores often designed, therefore, on the basis of convenience to customers, are

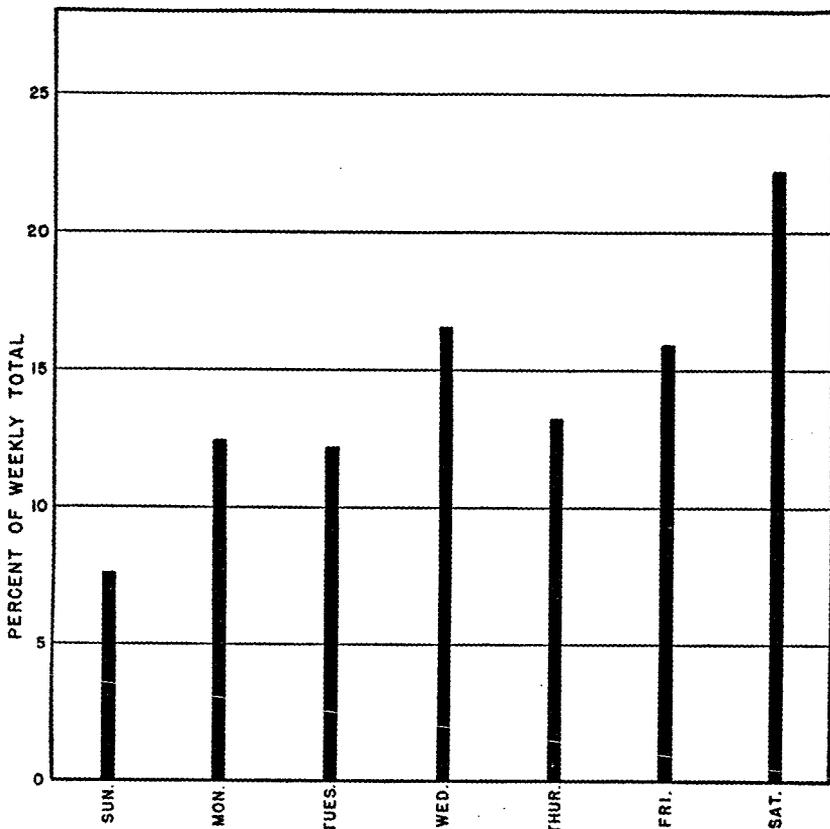


FIGURE 2. Daily Variation in Parking Activity

planned with sufficient capacity for Saturday peaks in considerable excess of the peaks on other days.

Hourly Variations

Variations in demand that are most significant to garage operators occur *during* the day. These variations, more sensitive to local conditions of business and weather, follow less predictable patterns. Different methods, therefore, were tried for charting in-

and-out movements and parking durations. The most concise and understandable charts showed (1) inbound and outbound movements by half-hourly periods, the accumulation of cars in the garage, and (2) the breakdown of parked cars by duration of parking and time of arrival. Numerous examples are shown.

The first type of chart shows data corresponding to the cordon counts of urban traffic. The time of occurrence and extent of peak-flows for each day can be readily seen. The degree of activity at different hours can be judged by the total movements, whether inbound, outbound, or a combination of the two. The accumulation curve indicates the extent to which space is used.

The second type of chart measures patronage by showing arrival-times. The series of bar graphs represents one-hour differences in duration of parking, indicating the percentage of daily inbound movements occurring during each half-hour period. Figures along the right-hand margin indicate the total percentage for each hourly change. A pair of such charts has been prepared for typical days in each of several garages which are identified and described in Table I.

Table I

CAPACITY AND OPERATION OF CERTAIN GARAGES

<i>Designation</i>	<i>Nominal Stall Capacity (Transient parkers)</i>	<i>Type of Parking</i>	<i>Number of Attendants (Drivers)</i>	<i>Type of Patronage</i>
"A"	800	Attendant	21	Shoppers
"B"	250	Customers drive on ramps. Attendants park cars.	11	Shoppers
"C"	425	Customer	—	Shoppers Theatre-goers Businessmen
"D"	300	Attendant	8	Shoppers Businessmen
"E"	350	Attendant	14	Shoppers

Daily Variations—Garage "A"

Daily variations in traffic patterns may be closely studied by comparing the hourly flows and the durations of parking. An analysis

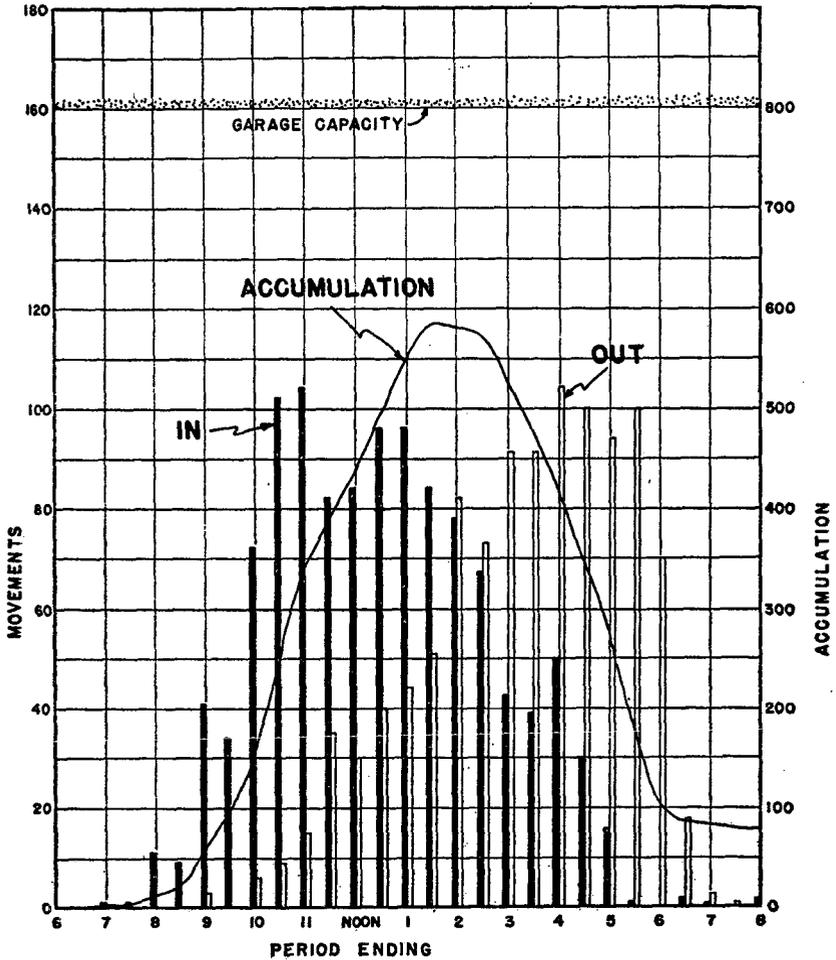


FIGURE 3. Garage "A"—Parking Characteristics for a Monday in May
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

of each day's movements in Garage "A" during a week in May is shown in the following Figures 3 through 8.⁴

Data as to peak and average movements are summarized in Table II. The greatest accumulation of cars occurred on Saturday, although at this particular time of year the garage was not

⁴This garage was not open on Sundays.

Table II

SUMMARY OF PEAK MOVEMENTS IN GARAGE "A" DURING WEEK IN MAY

<i>Day</i>	<i>Max. No.</i>	<i>Time of Max.</i>	<i>Max. No. in Hour</i>	<i>Time of Max.</i>	<i>Ave. per hour 10 am-2 pm</i>	<i>Max. No. in Hour</i>	<i>Time of Max.</i>	<i>Average 3-6</i>	<i>Max. No. In & Out in Hour</i>	<i>Time of Max.</i>	<i>Average 10 am-6 pm</i>
Monday	584	1:30 pm	206	10:00-11:00	181	204	3:30-4:30	186	300	1:30- 2:30	250
Tuesday	504	2:00 pm	161	11:30-12:30	141	180	4:00-5:00	151	234	3:30- 4:30	195
Wednesday	565	2:30 pm	176	1:00- 2:00	136	217	4:00-5:00	190	285	3:30- 4:30	228
Thursday	515	2:30 pm	164	10:00-11:00	142	185	3:30-4:30	167	251	1:30- 2:30	198
Friday	702	2:00 pm	252	11:00-12:00	212	251	3:00-4:00	221	359	1:30- 2:30	284
Saturday	709	2:30 pm	326	10:00-11:00	250	270	4:30-5:30	241	406	11:30-12:30	350

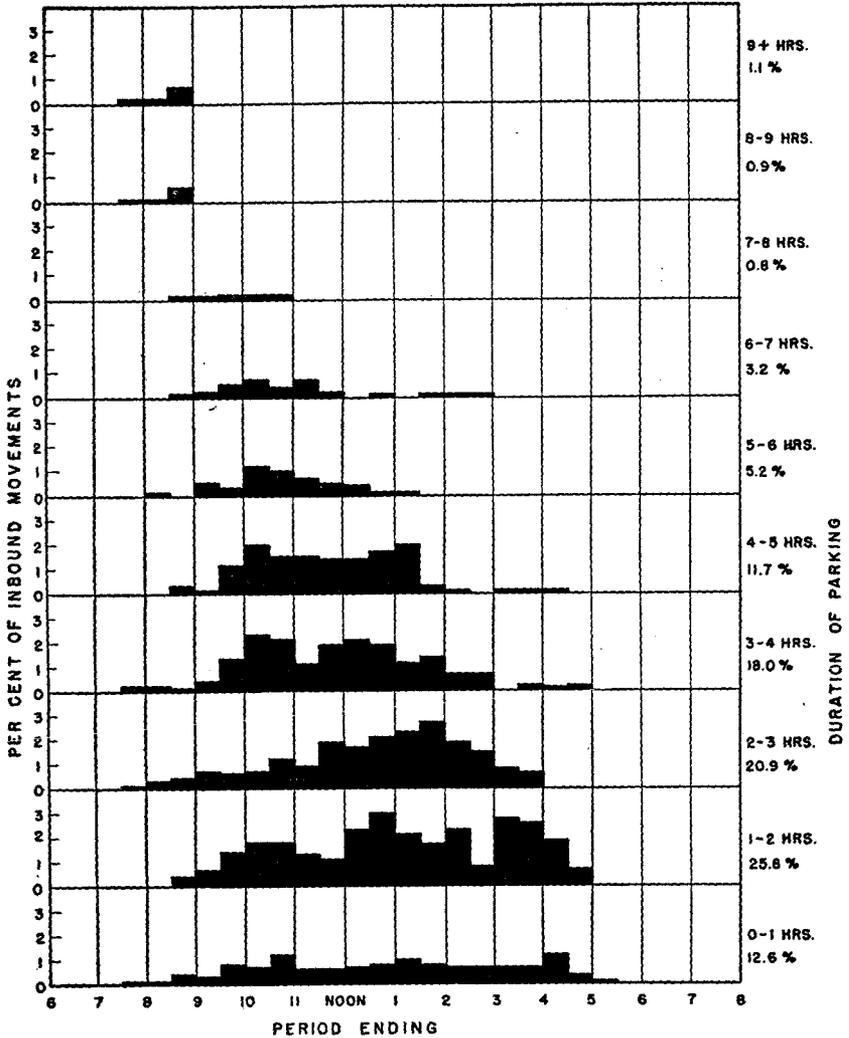


FIGURE 3

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

entirely filled. On Saturday also, the maximum accumulation occurred over a period of $3\frac{1}{2}$ hours, while on other days there was a sharp peak accumulation, after which the number of cars dropped off abruptly. The peak accumulation occurs each day

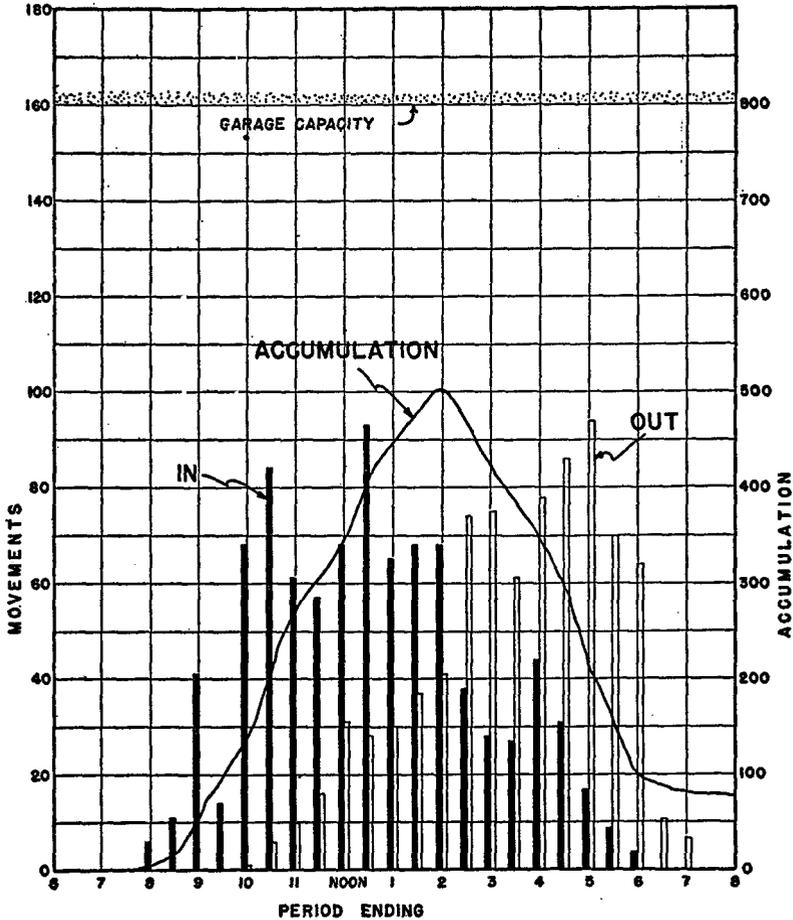


FIGURE 4. Garage "A"—Parking Characteristics for a Tuesday in May
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

between 1:30 and 2:30 P.M. This is generally the time of peak accumulation of persons in central business districts.

In all cases, the inbound peak movement occurs in the morning, the outbound peak in the afternoon. The heavy inbound movement, however, is neither as concentrated nor as regular as the outbound, and it may last into the afternoon, while the out-

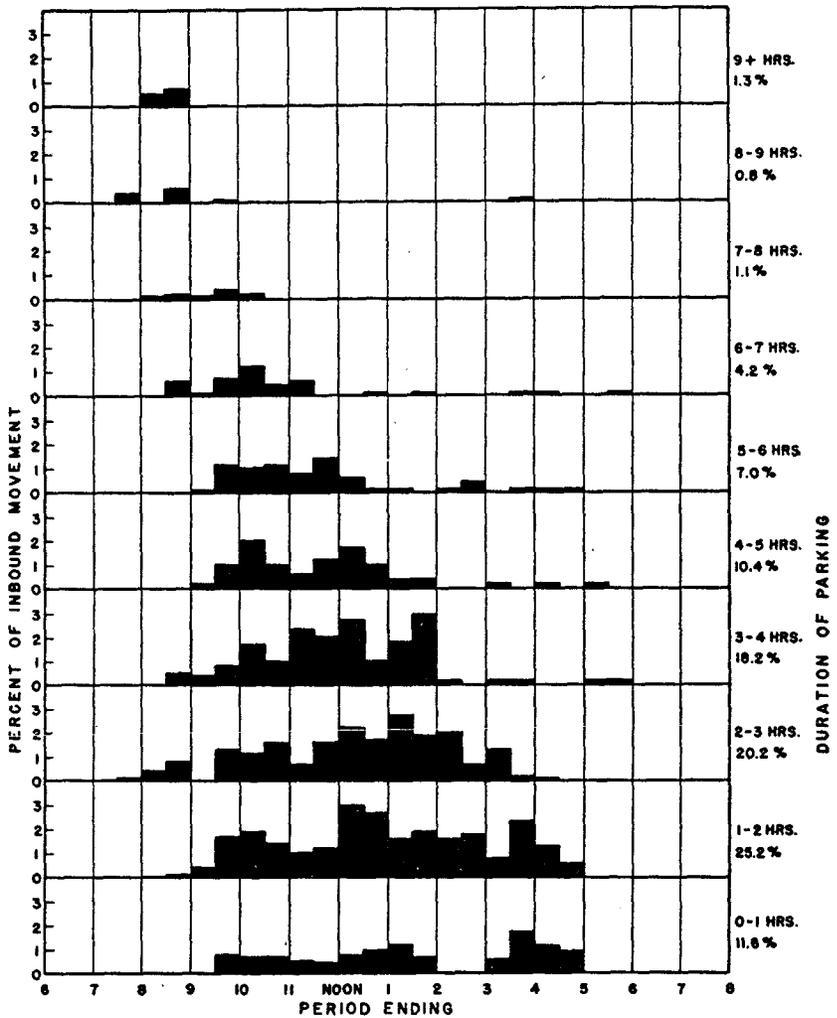


FIGURE 4

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

bound movement always builds up to a sharp peak in the late afternoon, falling off to a negligible amount at 6 P.M. On all days except Saturday, the average outbound movement is larger than the average inbound movement. It can be seen from Table

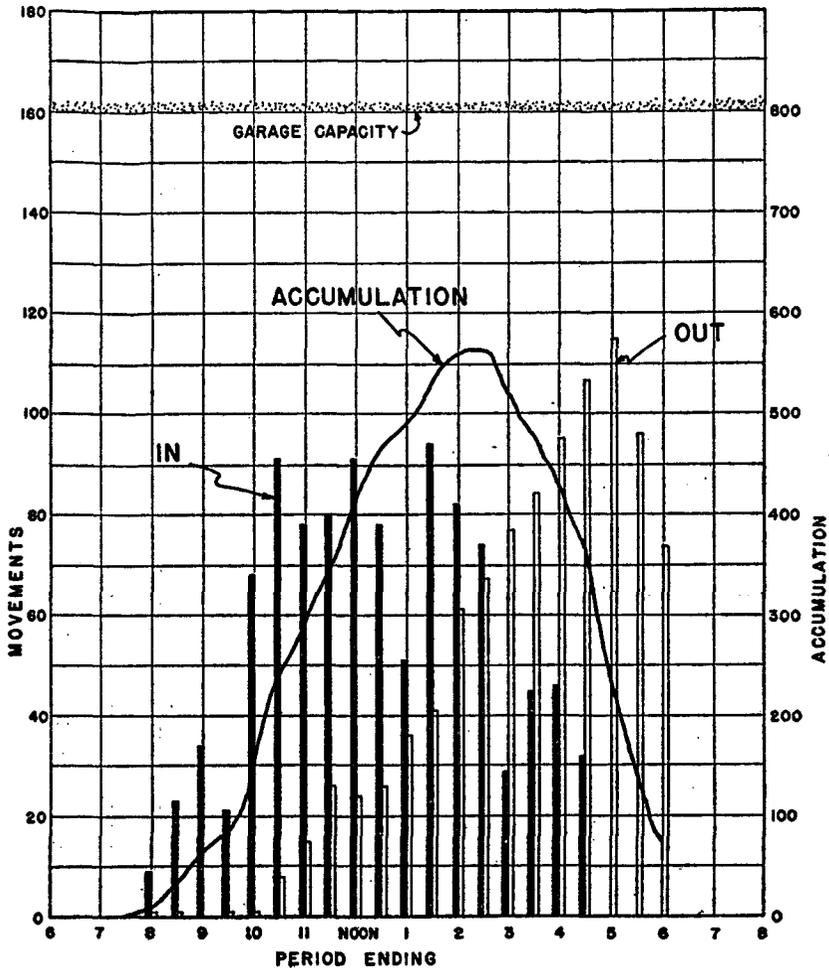


FIGURE 5. Garage "A"—Parking Characteristics for a Wednesday in May
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

II that the intensity of activity, as well as total volume, is greatest on Saturday, followed by Friday and Monday.

Analysis of the arrival times vs. duration of parking for this garage shows that in each case, the long-term customers arrive early in the morning and do not represent a large proportion of

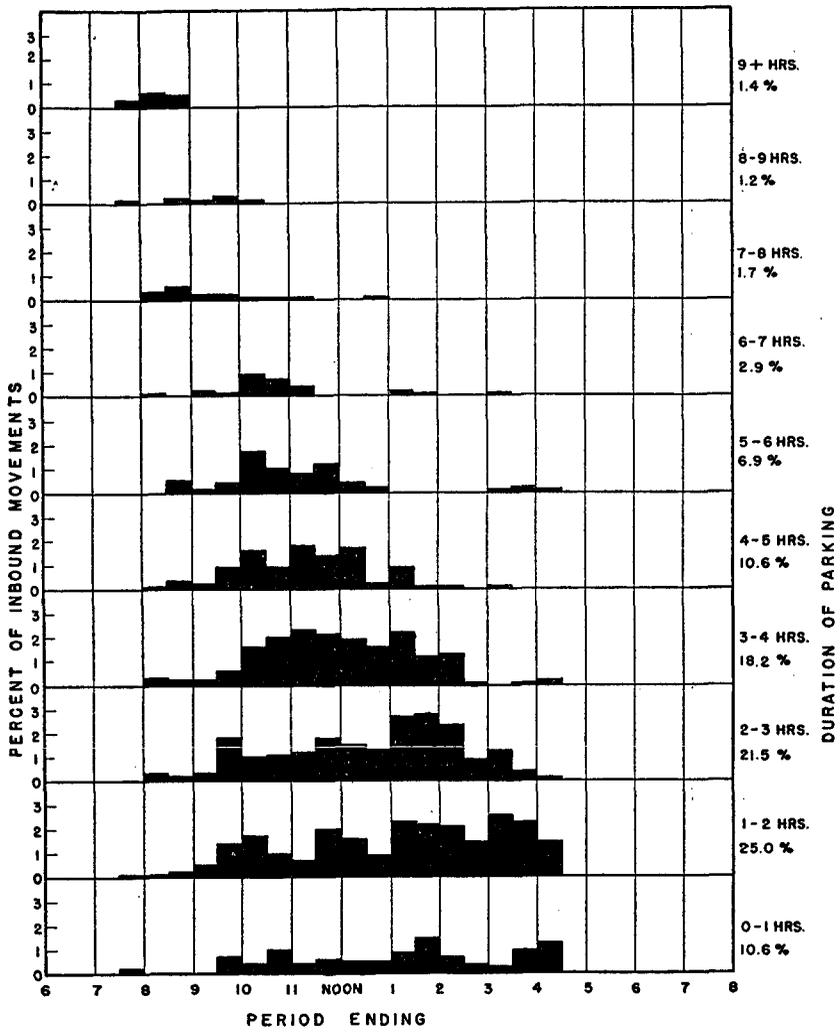


FIGURE 5

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

the total number of customers. The number of customers varies inversely with the length of parking, and the arrival times are spread over a longer period for the shorter-term parkers. The principal difference between days is the large number of rela-

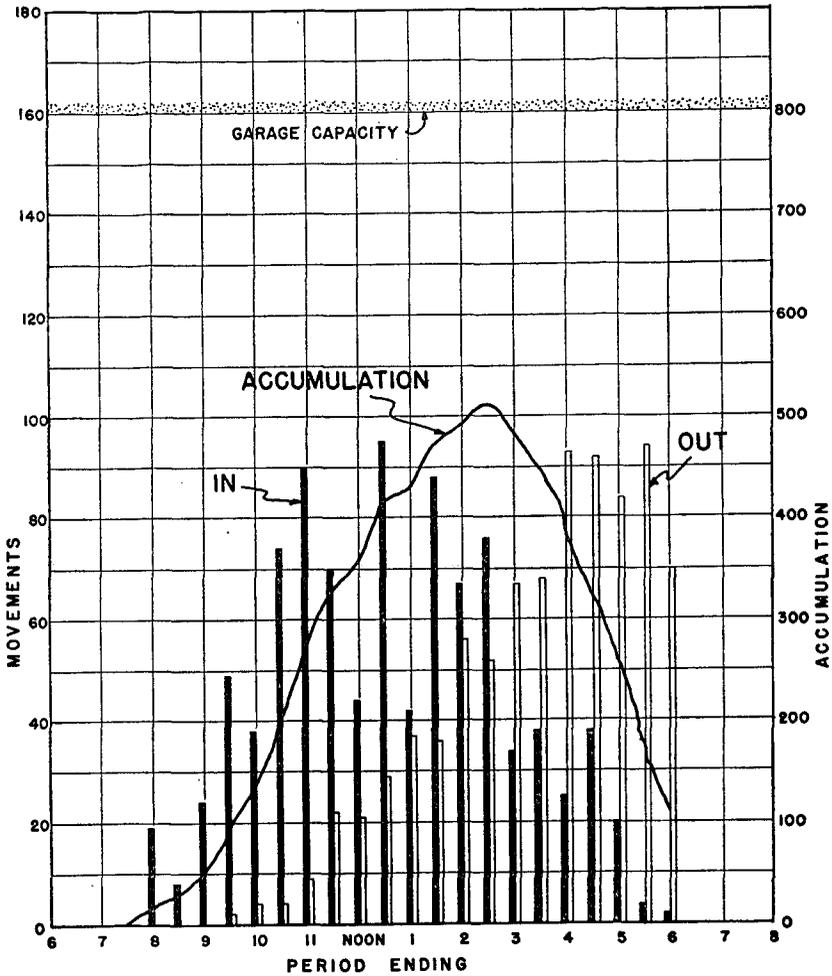


FIGURE 6. Garage "A"—Parking Characteristics of a Thursday in May
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

tively short-term (1 to 3 hour) parkers who arrive in the morning on Saturday.

Peak Rates of Movement—Garage "A"

One of the most important traffic factors in garage operation is the extent and occurrence-time of peak flows. A uniform flow can

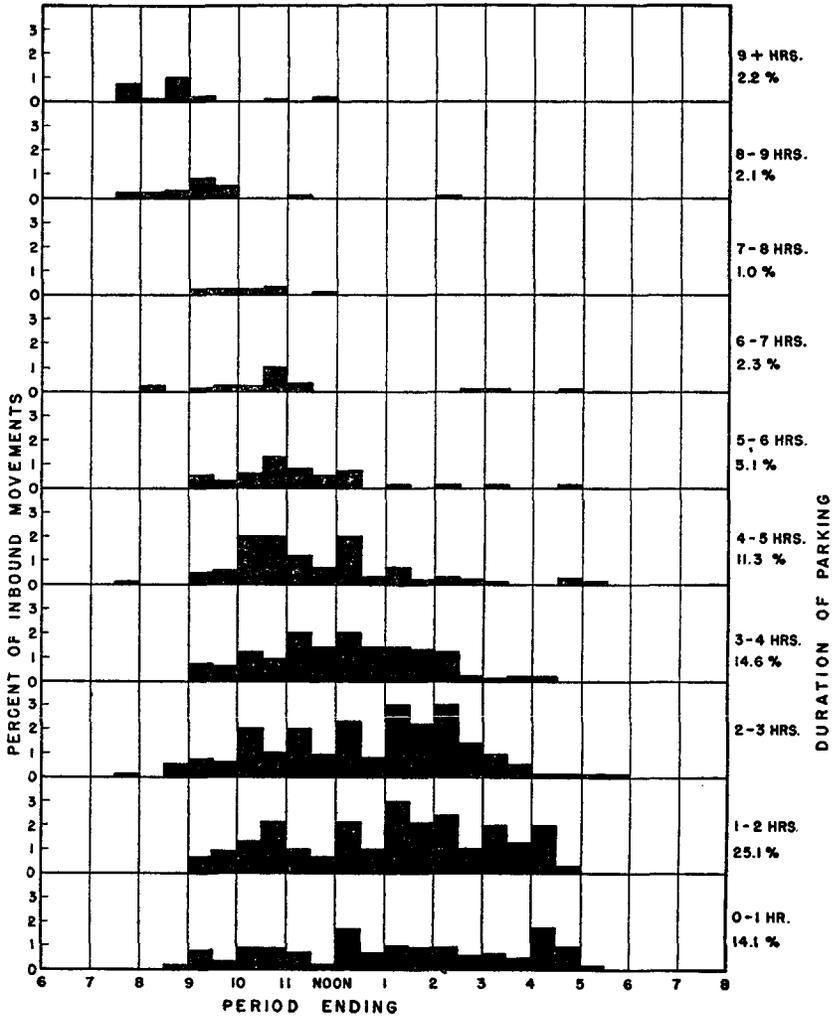


FIGURE 6

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

be handled most economically. Yet a basic fact of traffic-demand is that parkers arrive in short peak-periods and leave in even more sharply accentuated peaks. In order to retain parkers' patronage, garage operation must take care of peak flows, even if attendants

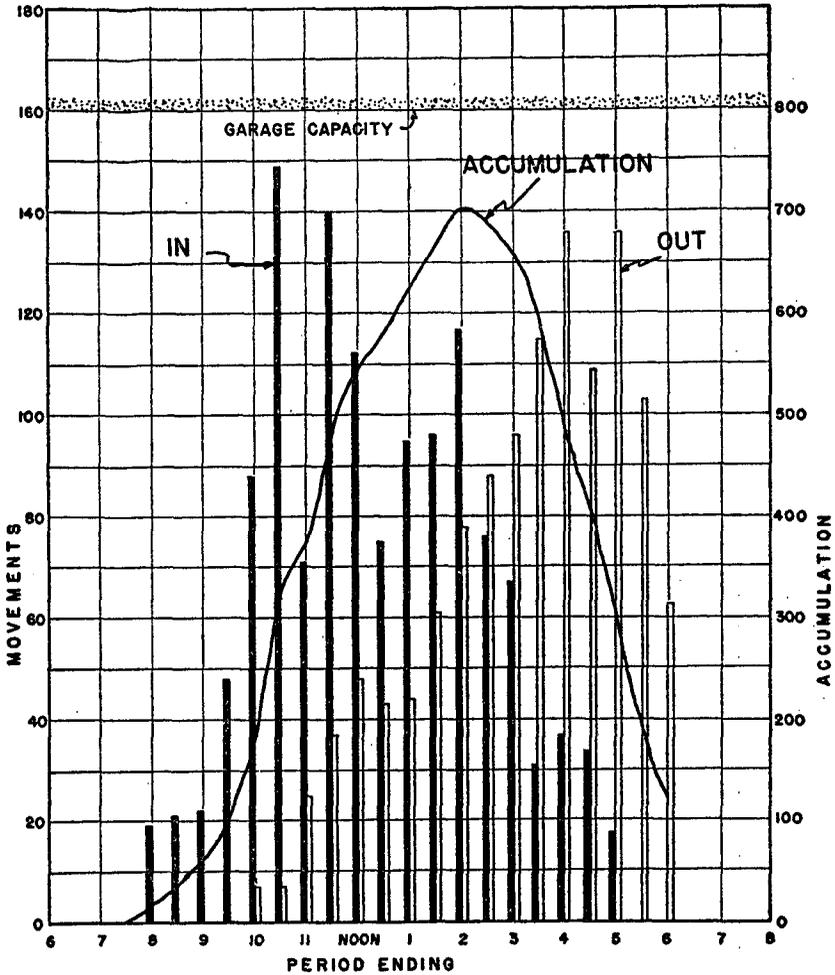


FIGURE 7. Garage "A"—Parking Characteristics of a Friday in May

a. Inbound and outbound movements, accumulation of cars by half-hour periods

and equipment are not fully used in intervening slack periods. If customers are dissatisfied in peak flows, the peaks and the revenue will both decline. As shown in Table II, the peak rates of movement recorded in Garage "A" for the week studied consisted of 326 inbound cars handled during the period 10 to 11 A.M.; and of

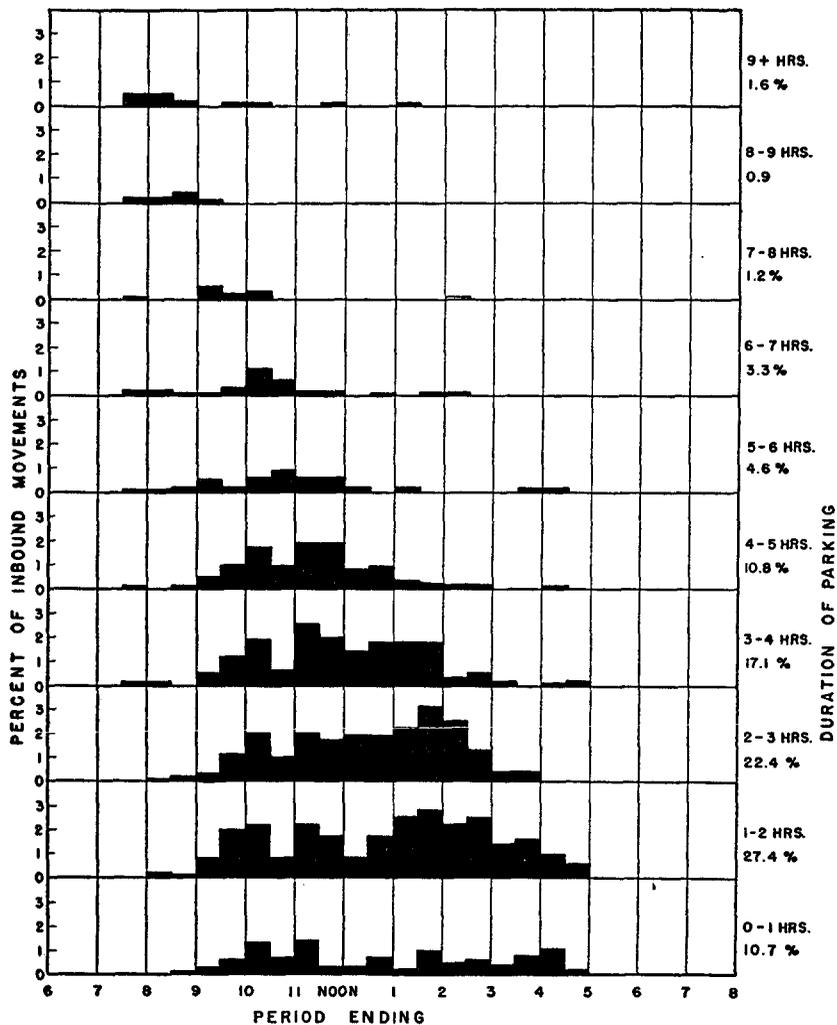


FIGURE 7

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

270 cars outbound between 4:30 and 5:30 P.M. on the same day. The largest number of cars handled—both in and out—during one hour was 406.

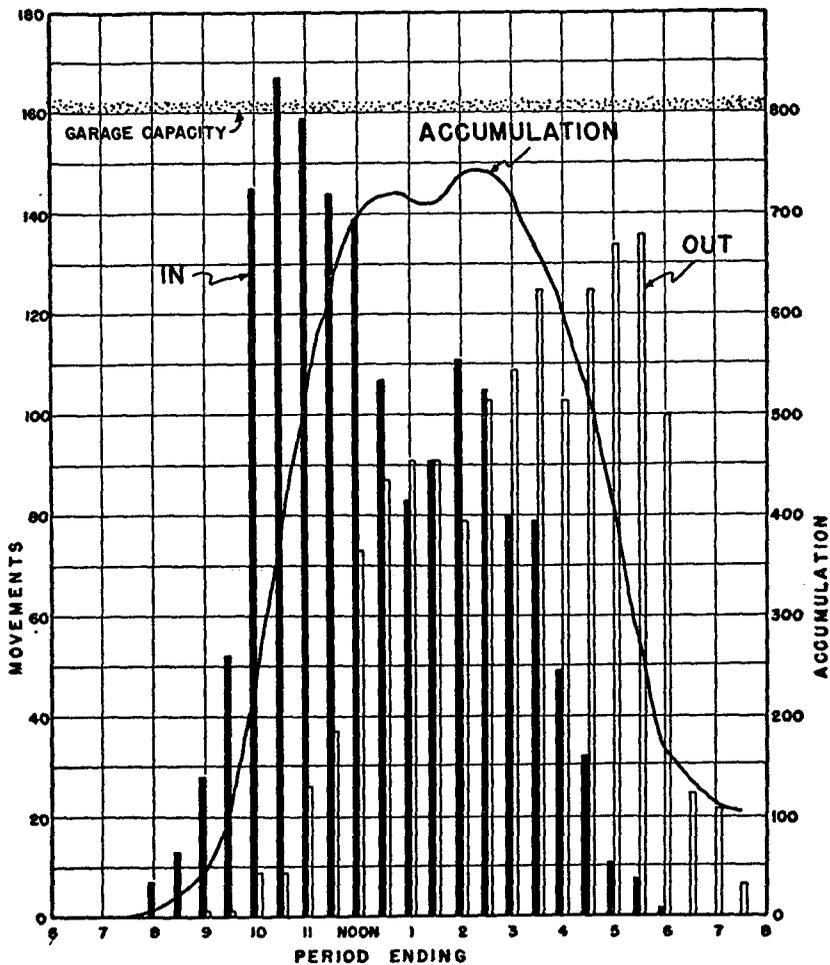


FIGURE 8. Garage "A"—Parking Characteristics of a Saturday in May
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

Expressed as a percentage of garage capacity, the peak flows are:

Inbound	39%
Outbound	32%

These flows are extraordinary, and can be obtained only by ex-

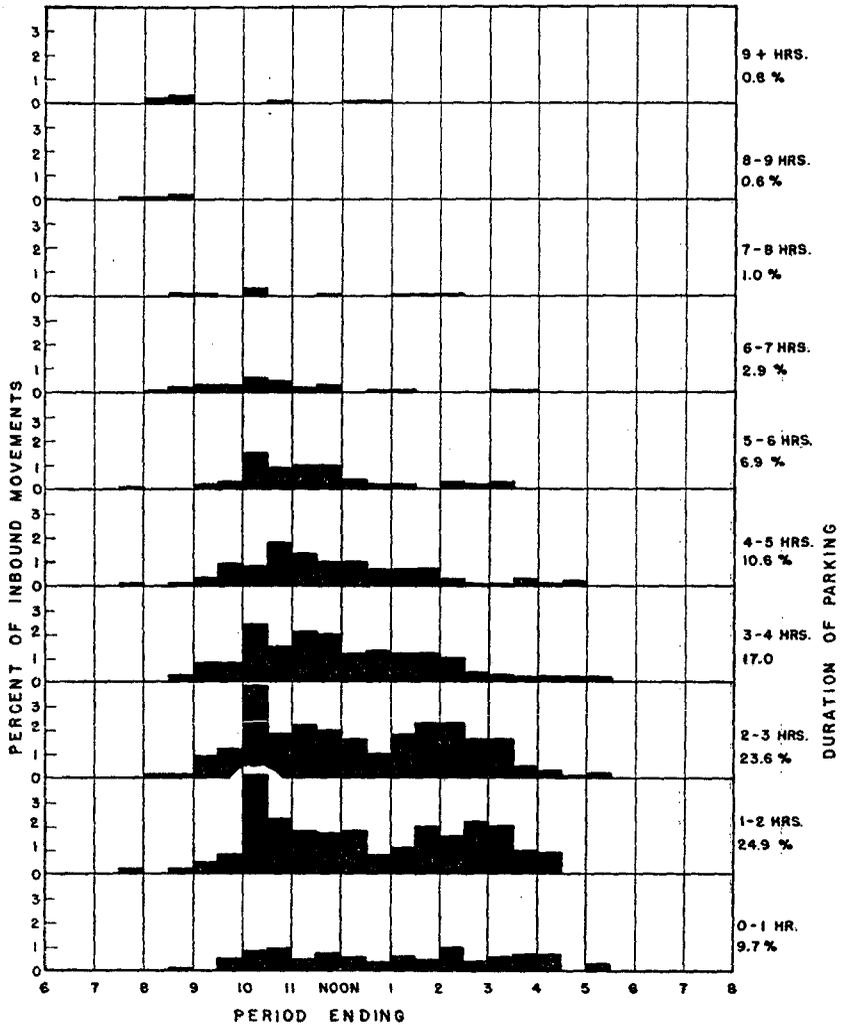


FIGURE 8

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

cellent operating methods, sufficient attendants, and liberal design, particularly in size of reservoir space.

The peak storage rate in this garage was 16 cars per attendant

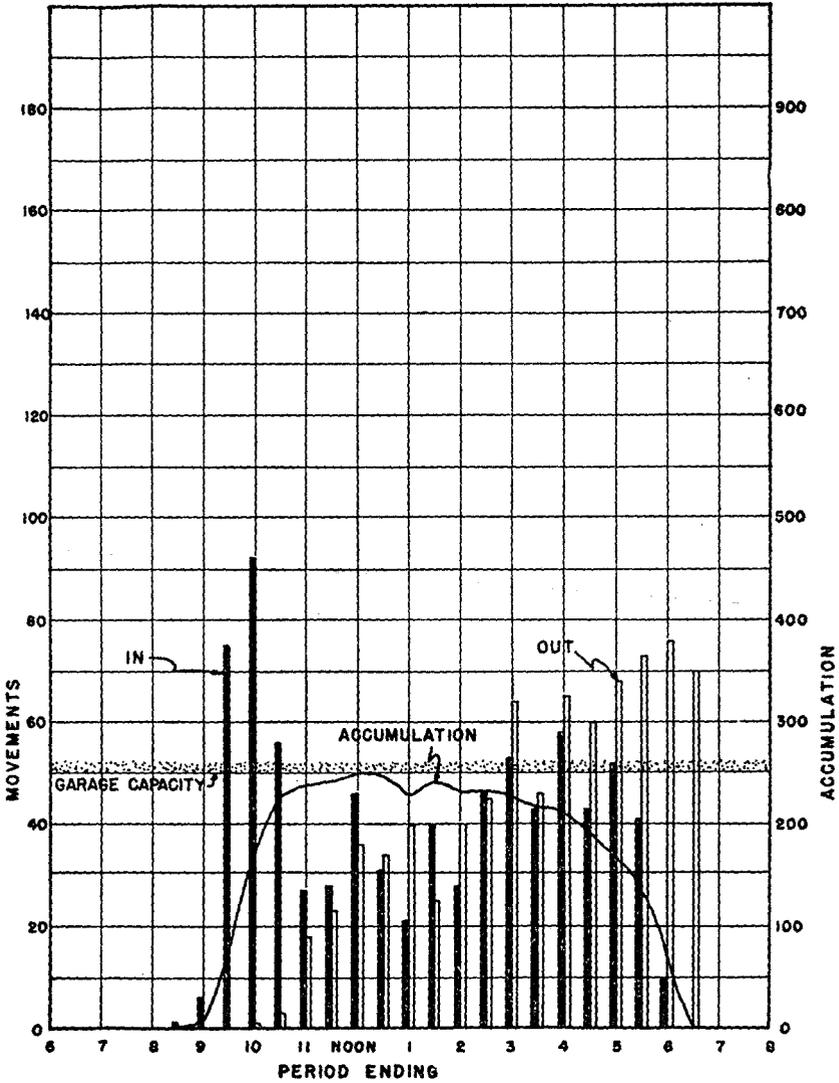


FIGURE 9. Garage "B"—Parking Characteristics for a Thursday in December
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

per hour, or 3 minutes and 50 seconds per car. The peak delivery rate was 13 cars per attendant per hour or 4 minutes 40 seconds per car. The average rates, during the busiest periods were 14.4

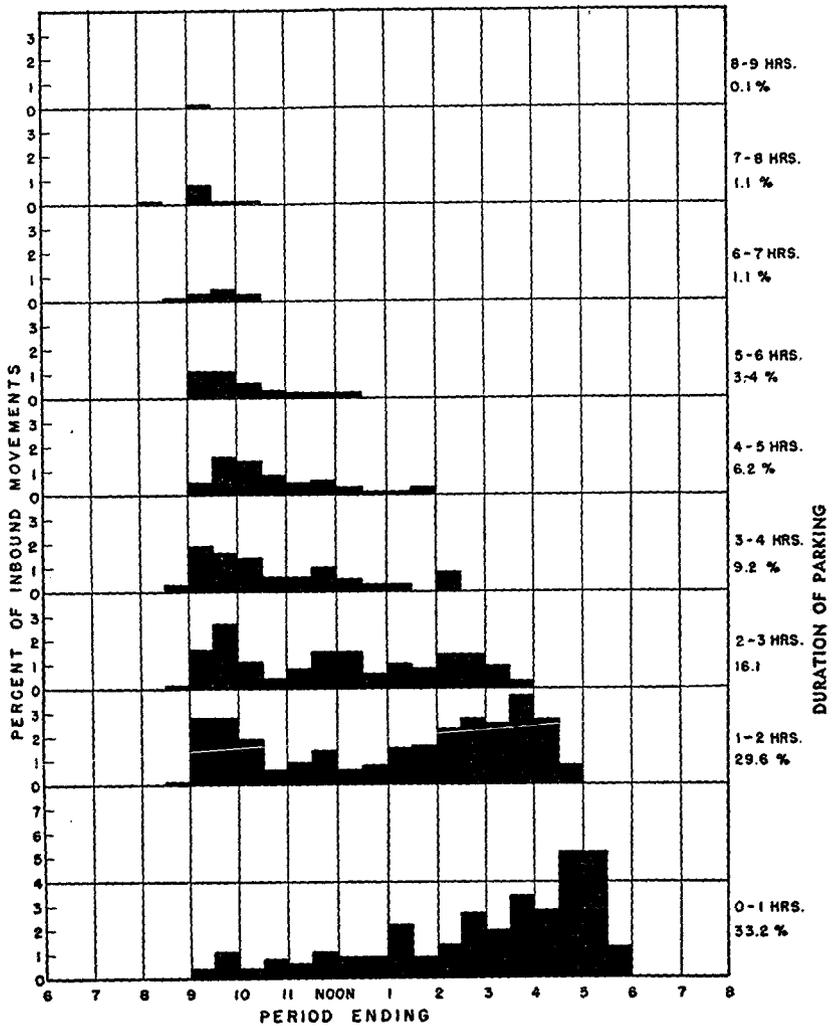


FIGURE 9

b. Percentage of cars arriving during half-hour periods, classified according to duration of parking

cars per attendant per hour inbound,⁵ and 11.1 cars per attendant per hour outbound.⁶

⁵9:30-12:00 Saturday.

⁶3:00-5:30 Saturday.

High Turnover—Garage “B”

Turnover may be expressed as the ratio of the number of cars parked during a period to the stall capacity. On a daily basis, the turnover in many garages is unity, or less, while curb stalls may have an average turnover of eight.⁷ In some very active shoppers' parking lots, a turnover of 10 cars per day has been experienced.⁸

Garage “B”, connected with a department store and operated as a service for the store's customers, is characterized by a low parking fee and a high rate of turnover. Figure 9 shows the movements for a Thursday early in December.⁹ It can be seen that it was filled nearly to capacity from 10:30 A.M. to 4:30 P.M. Most of the patrons were short-term parkers, 33.2 percent remaining less than one hour, 62.8 percent less than two hours. Each space was used an average of 3.2 times during the day. Because of this high turnover, both the in and out movements continued at a high level throughout the day, limited by the capacity of the garage. The peak inbound-movement was 167 cars an hour, or 67 percent of the capacity. This represents parking maneuvers of fifteen cars per attendant per hour. The outbound peak was 149 cars per hour, or 60 percent of the capacity, with an un-parking rate of fourteen cars an hour. Similar data for a Saturday shows no higher peaks in operation, probably indicating that the garage was operating at full capacity on this particular Thursday.

One reason for the high rate of turnover in this garage is the customer-attendant handling of cars. A more important reason is that the parking fee of 10 cents for the first hour is less than the initial fee charged in most garages. The duration-arrival-time chart shows that the shortest-term parkers, who would seem to be attracted by a low initial rate, arrive during the off-hours (9:00–10:00 A.M. and 3:30–5:30 P.M.) when accumulation is far below capacity in most garages. This group of parkers was not found in any of the other garages studied, as will be seen from the duration-arrival-time charts.

⁷*A Parking Survey of the Providence Central Business District, op. cit.* p. 23.

⁸*Condensed Digest of the Parking Clinic*, paper presented by Dudley W. Frost, City of Kansas City, Missouri, 1946.

⁹Adapted from data contained in student thesis by Edwin C. M. Lee, *op. cit.*

High turnover is desirable, both for revenue and because it relieves the outside parking problem. Data indicates that turnover can be increased by low initial rates and rapid service. A high turnover means intensified activity—more attendants, a large demand for reservoir space, more trips on the inter-floor driver-travel means. Some garages are not equipped for this type of service, and the operators must be content with a low turnover, mostly made up of all-day parkers.

Theatre Peak—Garage “C”

In addition to the normal daily and hourly variations in parking movements, there are generally factors that produce peak flows and durations peculiar to the surrounding district. Theatres, for instance.

Garage “C”, a customer-parking garage at the edge of a theatre district, has a variety of patrons, including shoppers, businessmen, and hotel guests. One of the features of the parking demand is the “theatre rush” inbound at 8 to 8:30 P.M. and outbound at 11 to 11:30 P.M. Figures 10 and 11 show the accumulation and

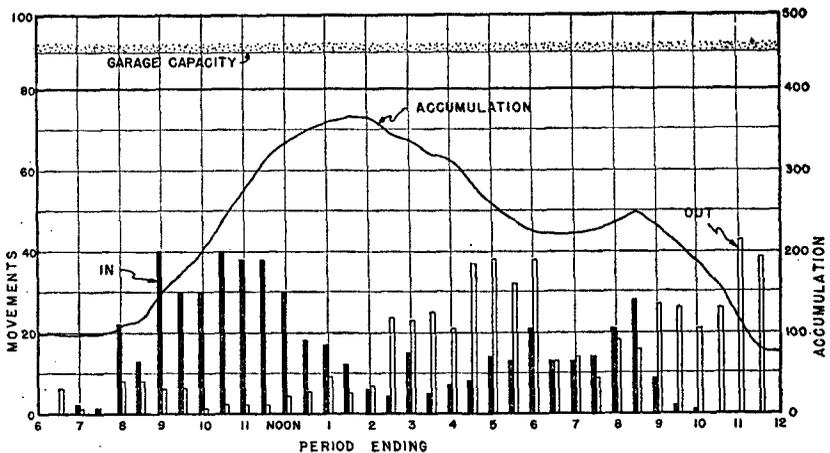


FIGURE 10. Garage “C”—Parking Characteristics for a Tuesday in March

- a. Inbound and outbound movements, accumulation of cars by half-hour periods

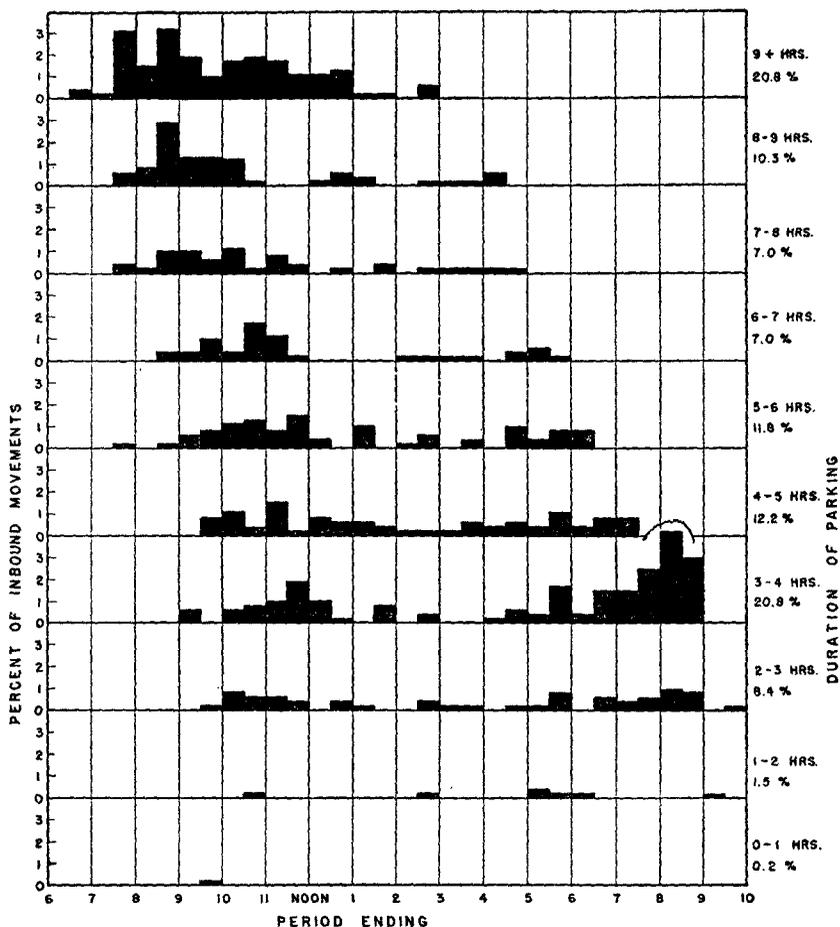


FIGURE 10

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

arrival-duration curves for a Tuesday and Wednesday in March. Wednesday was the busiest day of the week, because of matinees and because the local habit was to attend the theatres on Wednesday night. This characteristic is borne out by the charts, which show a greater daytime accumulation of 50 cars on Wednesday, as well as a greater evening accumulation of 100 cars. The peak flows shown are 115 cars an hour inbound, and 167 cars an hour

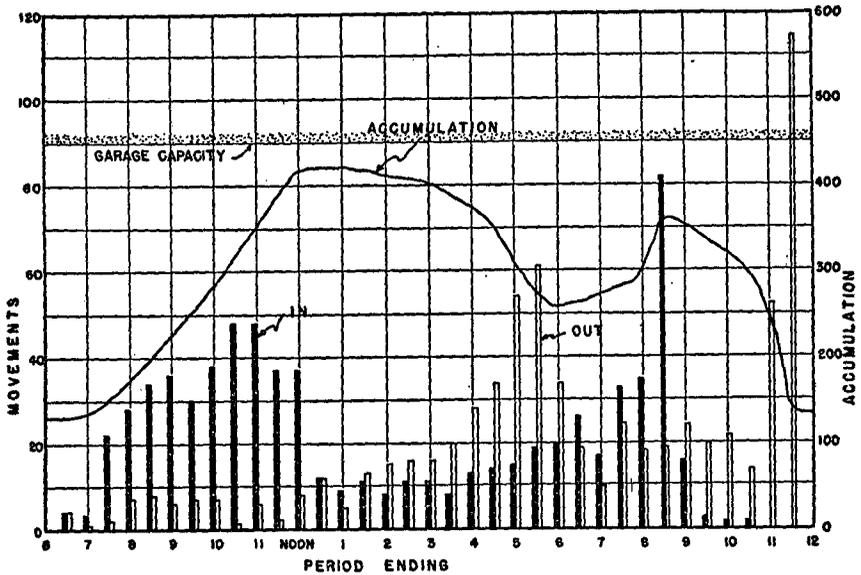


FIGURE 11. Garage "C"—Parking Characteristics for a Wednesday in March
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

outbound. These flows represent 27 percent and 39 percent of capacity an hour. The average inbound flow during the morning is 70 cars an hour, or 16 percent of capacity. The average outbound flow during the afternoon peak is 83 cars an hour, or 20 percent of capacity.

The occurrence of off-hour peaks of this type makes it difficult to schedule the working hours of employees. The time between the start of the morning inbound rush and the evening outbound rush is fifteen hours. This necessitates a double shift.

The duration-arrival charts for this garage show no particular pattern, except the relative importance of the long-term parkers. These represent about 30 percent of the total volume and arrive during the morning. The evening peak again is emphasized.

Evening Shopping Peak—Garage "D"

Another factor that distorts the normal pattern of parking is the late opening or closing of stores. This is illustrated by the charts

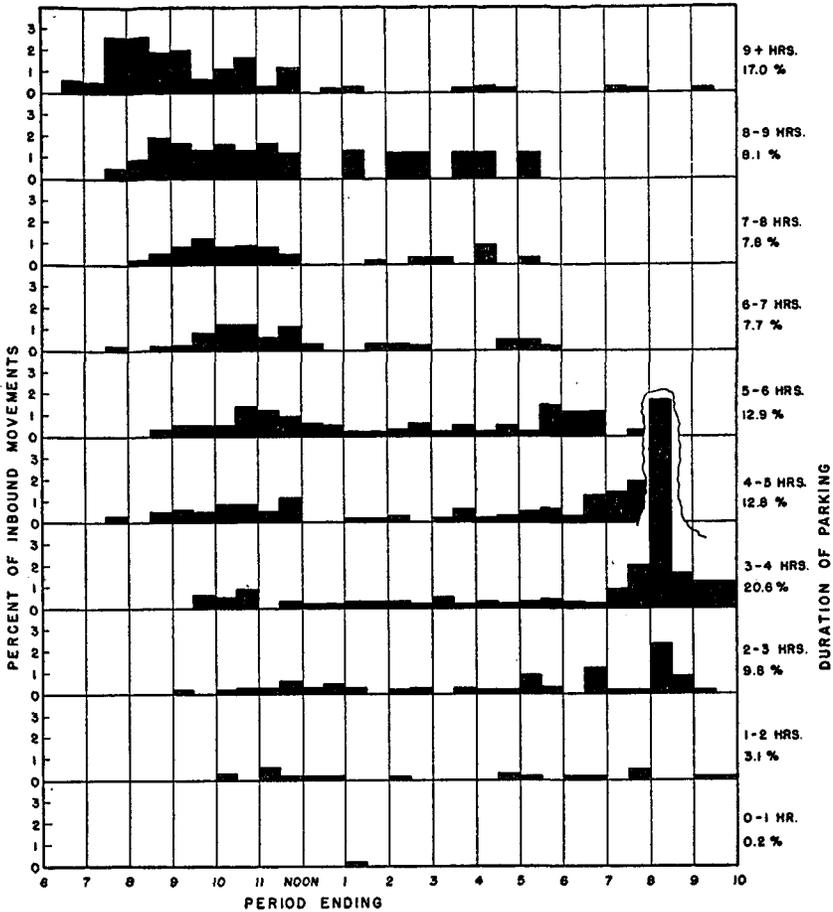


FIGURE 11

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

for Garage "D", located in the center of the shopping area of a large eastern city. Attendant-parking is used, and the garage is filled nearly to capacity on normal weekdays. Most of the important stores in the vicinity remain open until 9 P.M. on Wednesday, imposing a large evening load.

Accumulation and arrival-duration curves for this garage are shown in Figures 12, based on a May Wednesday. The normal pattern of outbound flows in the late afternoon is almost lost,

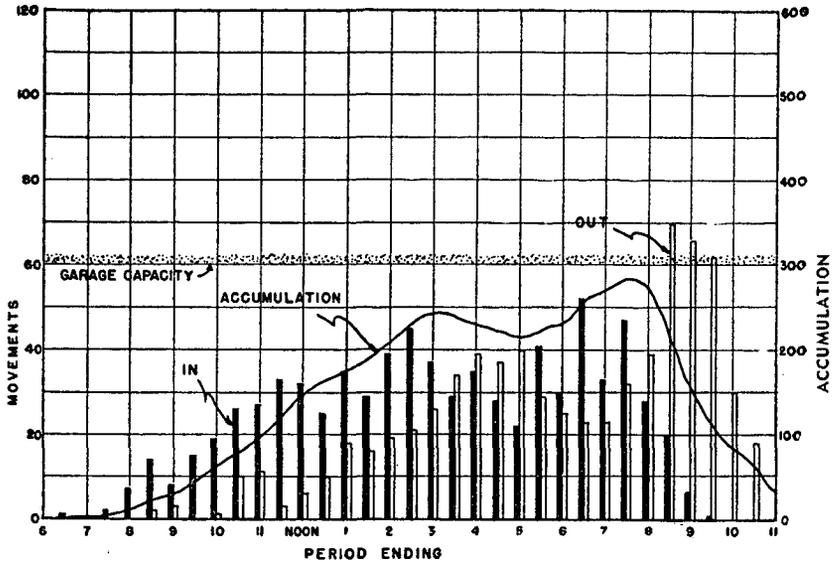


FIGURE 12. Garage "D"—Parking Characteristics for a Wednesday in May
 a. Inbound and outbound movements, accumulation of cars by half-hour periods

with the result that the accumulation curve dips but slightly, and then rises to an even higher peak. (A greater capacity for transient cars is available in the evening, because day-time contract parkers are gone)

The outbound flows from this garage are artificially limited by the rate of delivery, and are equal to 136 cars an hour, or seventeen cars per attendant per hour. The demand for delivery was much greater, perhaps at the rate of 200 cars an hour. The peak inbound flow was 84 cars an hour, or about fourteen cars per attendant per hour. In terms of garage capacity, the peak hourly inbound flow is 25 percent, and the peak outbound flow is 41 percent.

This type of peak operation is easier to handle than the theatre peaks discussed in the preceding paragraph. It is predictable in occurrence, and since it happens only once a week, and rather early in the evening, regular employees can be held overtime to handle it.

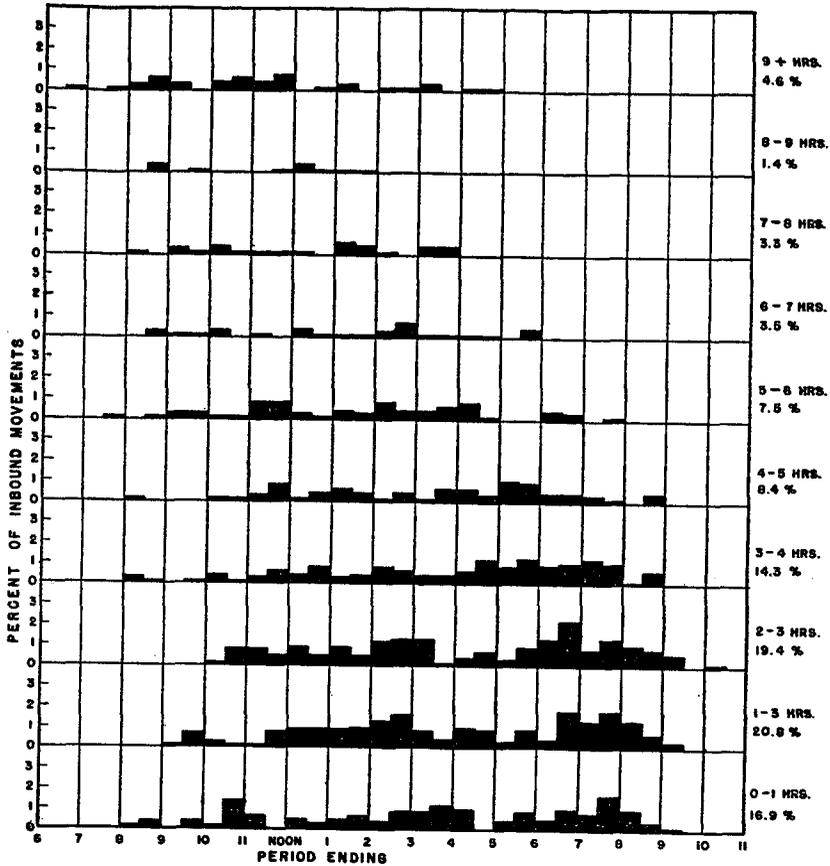


FIGURE 12

b. Per cent of cars arriving during half-hour periods, classified according to duration of parking

Normal Shopping Load—Garage “E”

The pattern of inbound and outbound flows and accumulation shown in Figure 13 may be considered normal for an average weekday in a shoppers' garage. It is based on Garage “E”, an attendant-parking garage operated for patrons of a large department store. The data are averaged for a Tuesday, Thursday, Friday, and Saturday in November; Monday and Wednesday were excluded because the department store is closed Monday morn-

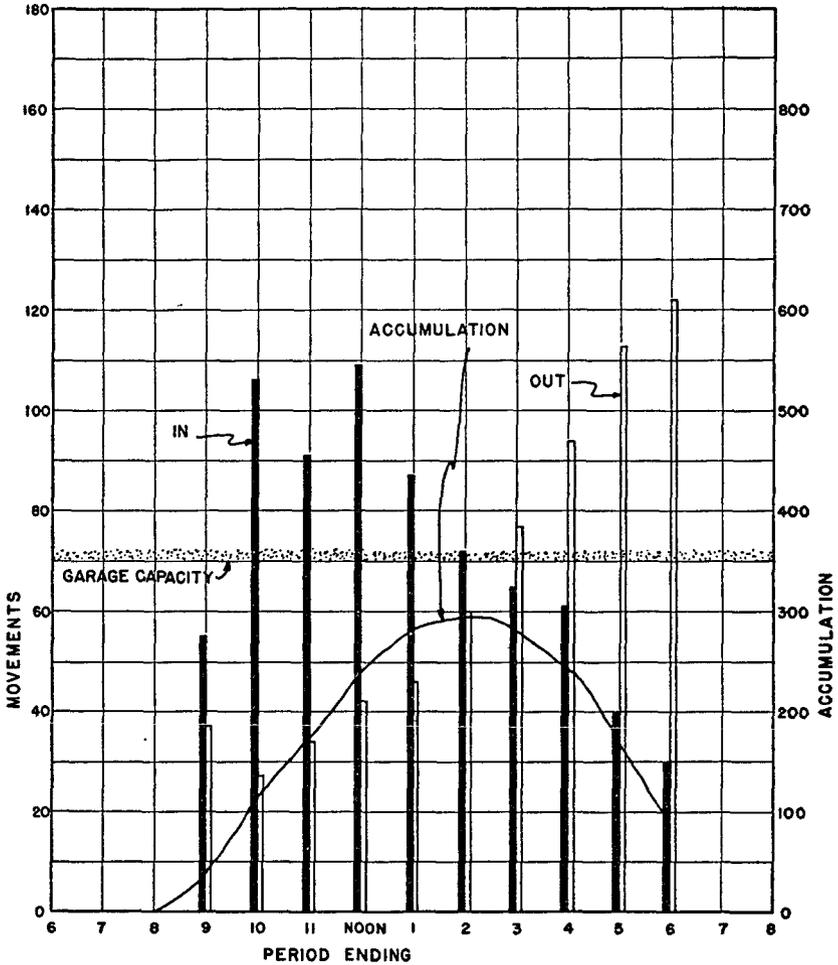


FIGURE 13. Garage "E"—Parking Characteristics—Average of Normal Weekdays in November

Note: Movements are shown on an hourly basis

ing and open late on Wednesday evening. (This garage is situated in the same city as Garage "D")

The peak rate of arrival is 109 cars an hour, or 38 percent of capacity, which represents a handling of eight cars per attendant per hour. The peak rate of delivery is 122 cars an hour, or 43 per-

cent of capacity, with a handling of fifteen cars per attendant per hour.

During peak periods on busy days, this garage has a large unfilled demand, and many customers are turned away, requiring one or more municipal policemen to control the excess and prevent the cars from standing in the street.

City-Wide Parking Demand

Parking operation factors in individual garages have been discussed in previous paragraphs. For city-wide approaches to the

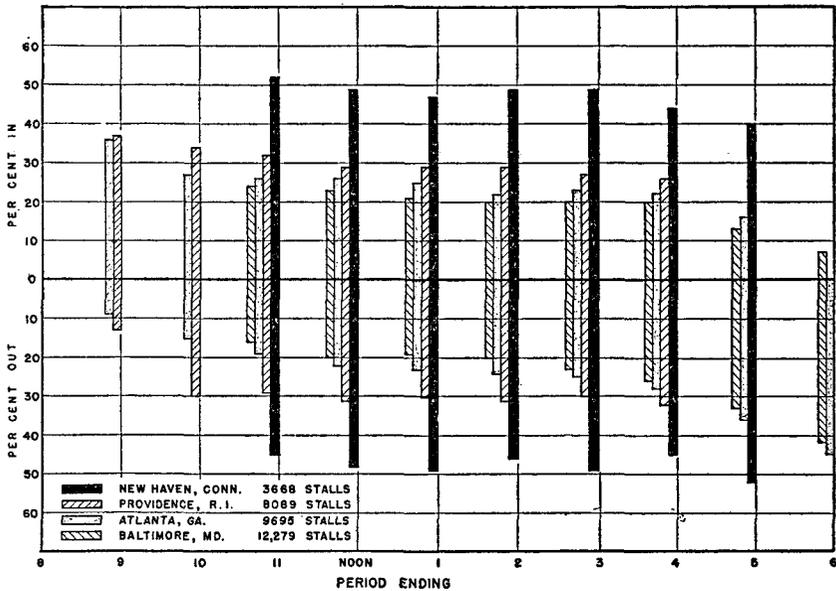


FIGURE 14. Movement of Cars In and Out of Parking Facilities in Central Business Districts by One-hour Periods, Expressed as a Percentage of Total Stall Capacity

Note: Data computed from published reports of parking surveys, viz:

New Haven Parking Study, Connecticut State Highway Department 1947.

A Parking Survey of the Providence Central Business District 1945, Rhode Island Department of Public Works and Public Roads Administration.

Atlanta Parking Survey, State Highway Department of Georgia and Public Roads Administration, 1946.

Parking Survey of the Downtown Area—Baltimore City, Maryland State Roads Commission, 1946.

parking problem, the study may be broadened to determine the rates of inbound and outbound movement, the accumulation, and duration of stay for all parking spaces in the central business district. As the parking problem approaches some solution, it is probable that many curb stalls will be replaced by off-street facilities. Unless this produces a basic change in the habits of the average parker, the "new solution" garages and lots must be prepared to meet the high rates of turnover now found at the curb, and must have low handling times in the acceptance and delivery of vehicles. *If they do not*, the average motorist may forego parking in these garages or lots and either park illegally at the curb or patronize suburban "decentralized" areas.

Present habits of curb-parkers and others in central business districts may be studied through parking surveys. As an example, data have been extracted from the reports of surveys made in Providence, Atlanta, New Haven, and Baltimore, shown in Figure 14. In each case, a computation has been made of the number of cars entering and leaving stalls during each one-hour period, expressed as a percentage of the total stalls of all types.

The rates of parking and unparking are almost constant throughout the day, when considered on the basis of all facilities in the central business district. The incoming flow decreases gradually in the afternoon; the outbound flow increases. It is unfortunate that the data do not cover the whole business day for any one city: peak flows may thus be missing. The greater values shown for New Haven in every case may be due to the selection of a relatively small area for study. Thus a greater activity may be expected. There is in addition a certain error in all of the curb-parking values introduced by the inclusion of illegal parking movements, for which no corresponding number of stalls is shown in the capacity figures.

As a general conclusion, it may be stated that the number of cars parking and unparking during each hour will be from 25 to 45 percent of the total number of available stalls.

DEMAND FOR DELIVERY OF CARS

The charts and discussion in the foregoing paragraphs have touched upon the rates at which cars are delivered to customers.

In a sense, this is a traffic factor, because it indicates the number of cars that can be expected to emerge into the street traffic stream during different periods. In most cases, however, the rate of delivery of cars is fixed by the internal processes of the garage, and not by actual customer demand, which is the true characteristic. This latter factor must be measured by different methods. Highway traffic movements have been found to follow closely the Poisson series of random distribution, a fact that allows the application of the theory of probability to the solution of traffic problems.¹⁰ A similar correlation may be expected for certain traffic and customer movements connected with garage operation, such as the arrival time of inbound cars and the arrival time of customers calling for their cars.

RANDOM NATURE OF ARRIVAL

If customers arrive at a garage on some predictable basis, that fact can be determined by making an accurate record of their arrival times and comparing the intervals between arrivals with those predicted by the Poisson Theory. Counts were made in several garages of the arrival time of customers at the cashier's cage or

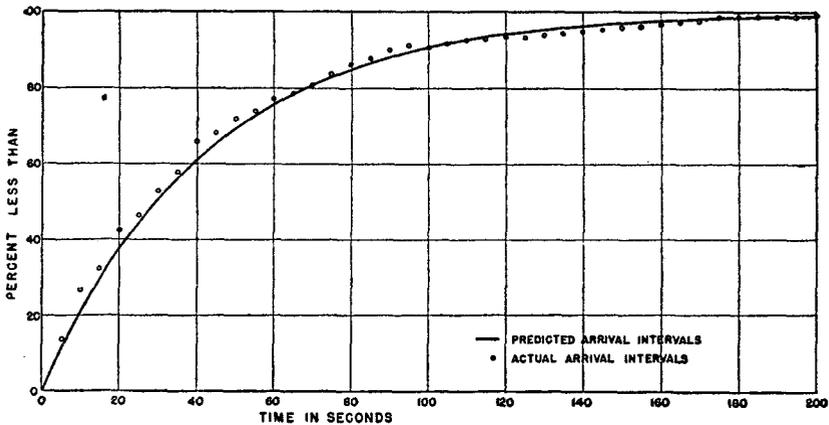


FIGURE 15. Cumulative Time Spacings Between Arrival of Customers in Cashier's Line. 198 Customers Arriving in Two Hour-Fifteen Minute Period. Garage "D".

¹⁰*Traffic Performance at Urban Street Intersections*, Bruce D. Greenshields et al, Yale University, p. 73.

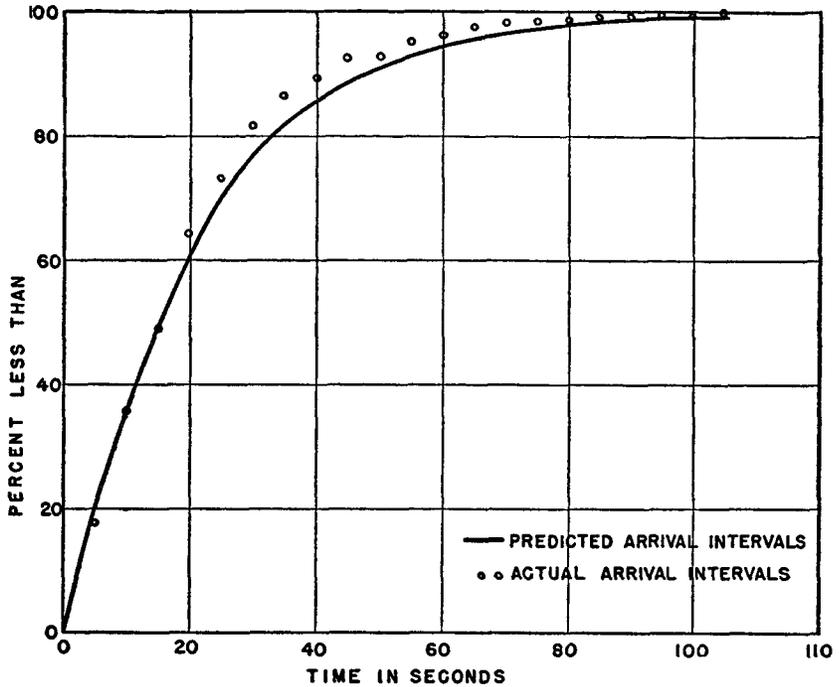


FIGURE 16. Cumulative Time Spacings Between Arrival of Customers in Cashier's Line. 167 Customers Arriving in One Hour Period. Garage Primarily Serves Business Executives.

in line at the cage. The results of two of these counts are shown in Figures 15 and 16; actual arrival-intervals are compared with those that might be predicted by the theory of probability or Poisson's formula. In both instances there is close agreement, indicating that the theory of probability can be applied to the arrival time of customers. Without elaboration of this theory, it may be said that, if the average rate of arrival of customers is known, the maximum number arriving during an interval may be predicted.

MOVEMENT INSIDE GARAGES

Parking demand factors previously discussed have been concerned with groups of parkers—how many arrive during a given

hour, the average duration of parking. Underlying all of these characteristics, and of vital importance in analyzing garage operations, are the movements of individual cars within the garage. Although garages are built for the *storage* of cars, the convenience, safety, and speed with which cars may be *moved* into and out of storage determine the functional and economic success of the parking operation.

In an attendant-parking garage, the customer drives into the reservoir space, receives his parking check, and walks out. This transfer of responsibility from the customer to the garage is almost independent of the other steps in storing a car, since it involves personnel other than attendants, and may take place at a faster or slower rate than the other steps. If the garage is filled to capacity, or the reservoir space is overloaded, the customer may have to wait to enter the garage.

The time required for issuing identification tickets varies with the type of ticket used, and particularly, the amount of information required. At one garage studied, where a simple (and, incidentally, unsatisfactory) ticket system was used, a floor-man issued 175 tickets an hour. Whenever service-sales are made when tickets are issued, a longer time is obviously required. The average time is about 30 seconds a car, so that a floor-man can issue 120 tickets an hour.

In this study, the first step of the attendant parking movement is measured from the time the attendant places his hand upon the door handle, and ends when the car moves. Attendants perform this operation in an impressively short time, though in cold weather or with defective cars, a longer period may be required. The average time in this study was eight seconds.

Customers require a longer period. The average get-in-and-start time was clocked at nineteen seconds. There are several reasons; such as the comfort of the driver and his concern for the mechanical condition of his car.

The stopping operation does not involve the mechanical condition of the car, requires less time, and is more consistent. It occurs, when the car is parked, moved between stalls, or delivered. The average time measured for attendants to stop a car, set the brake, turn off the ignition, get out, and close the door was six seconds.

Travel Speed Inside Garages

Customers drive more slowly than attendants. Speeds vary between floor-driving and ramp-driving, and with other factors, such as sight-distance.

Attendant-travel for unobstructed movement on most types of ramps was about 12 miles an hour both up and down. Inexperienced attendants drive more slowly; no ramp-speeds in excess of fifteen miles an hour were measured. The travel time on ramps of average length is thus about 8 to 12 seconds a floor. The travel speeds on storage floors depend largely upon the distances traveled and the number of turns involved. Speeds on long straight aisles may reach 16 or 18 miles an hour; more generally about thirteen miles an hour.

The speeds of customer-parkers have a much wider range; experienced drivers fall into attendant-speed categories, timid drivers into markedly slow classes. Speeds on up-ramps in all cases were higher than the speeds on down-ramps, a characteristic not found with attendant parkers. Customer-speeds also fluctuate with the type of ramp. Average speeds on different types ranged from five to twelve miles an hour for up-travel and from four to eight miles an hour for down-travel.

The acceptance or delivery of a car requires a great deal of movement on foot. The distance traveled by an attendant for each parking operation is about equally divided between driving and walking. The average walking speed of attendants was found to be five feet a second. In terms of elapsed time, this means that each foot of extra travel distance requires 0.2 second.

Parking and Unparking

Although cars may be parked in different angles and directions with respect to the access aisles, the only type found in the garages studied were right-angle stalls into which cars were backed. Parking time varied with stall and aisle widths. Time-measurements of the parking maneuver were begun when the car started in the aisle and ended when it stopped in the stall. For *adequate-sized* stalls, the average parking times were fifteen seconds for attend-

ants and thirty seconds for customers. Much greater parking times are required when narrow stalls or aisles necessitate several back and fill movements.

The parking and unparking movements have complementary time values. Cars may be driven into stalls faster than they can be backed in, but the time lost in unparking will compensate for the time saving. For 90° back-in stalls of adequate size, the unparking time was negligible. Once the starting movement was made, cars could clear the stall and accelerate in almost the same time as they could from an open area. Again, narrow stalls or aisles will require appreciable time for unparking.

(The vertical travel of drivers is discussed in Chapter VII. For the present chapter, it is sufficient to report that time-values developed there are: twelve seconds a floor on stairs, seven seconds a floor for service elevators, and 2.5 seconds a floor for fire poles. The waiting-time plus travel-time in passenger elevators is about one minute for the average number of floors)

Time Required for Storage

The attendant-storing rates of ten to fifteen cars an hour in most garages correspond to individual handling times of four to six minutes a car. The highest rate reported in a large garage was twenty cars per attendant per hour, or three minutes a car, and in one small garage a time of two minutes a car was reported. These values are measured for the round trip of an attendant in storing a car, and do not include ticketing or other reservoir-space operations.

An extensive series of measurements for the individual movements in one particular attendant-parking garage yielded consistent results. They are summarized as follows:

Get in and start	8 seconds
Driving on main floor	4 seconds
Ramp driving (average 2 floors at 12 seconds a floor)	24 seconds
Average delay on ramp	15 seconds
Driving on storage floor	6 seconds
Parking	18 seconds
Stop and get out	6 seconds

Noting location of car on office stub	31 seconds
Attendant walking to service elevator (average 2 floors at 7 seconds a floor plus 6 seconds waiting time)	45 seconds
Attendant going down service elevator	20 seconds
Attendant walking to reservoir space	8 seconds
	<hr/>
Total Time	185 seconds

TIME REQUIRED FOR DELIVERY

In any one garage, the times required for storage and delivery are about equal. Several operations—ramp-driving, floor-driving, walking, interfloor travel—are the reverse of each other. Other operations about offset each other, as parking requires more time than unparking, but the process of finding the desired car has no counterpart in the storage operation. In line with these considerations, the delivery time may be expected to range between two and six minutes, with modal values of three to four minutes.

For the same garage discussed above, the following component values for delivery time were found:

Obtaining ticket	5 seconds
Walking to service elevator	8 seconds
Riding up service elevator	20 seconds
Walking to stall	45 seconds
Checking location of car	20 seconds
Get in and start	8 seconds
Driving on storage floor	8 seconds
Ramp driving	24 seconds
Average delay on ramps	15 seconds
Driving on main floor	6 seconds
Stop and get out	6 seconds
Delivery to customer	10 seconds
	<hr/>
Total time	175 seconds

When there is a demand for storage and delivery at the same time, attendants can save time by driving one car to the storage floor and another one back to the main floor. The round-trip time per attendant is increased, but the time per car handled is reduced. In several different garages a relationship was found which

indicates that a combined storage-delivery trip requires about fifty percent more time than a single-purpose trip. Thus, if an attendant can store or deliver a single car in an average time of four minutes, he can store one and deliver another in about six minutes.

SUMMARY

The most important traffic factors of garages are the gross amount of parking demand, the time of occurrence of peak inbound and outbound movements, the duration of parking, and the rates at which cars can be stored and delivered. Some pre-determination of these values will greatly aid in the design of new parking facilities. Analysis of the same characteristics in existing garages enables a measure of the efficiency of operation.

The average values shown for typical movements can be applied to the analysis of garage designs, and a rough estimate made of the time which will be required for the storage and delivery of cars.

CHAPTER IV

DESIGN OF MAIN FLOOR

Many design features of parking garages, such as ramps and aisles, are so inter-related as to make distinction and separate analysis difficult. Differences in various designs are often minor, and no handbook of commonly accepted terms is in use. The definitions offered are products of the present study; they are not stated for acceptance throughout the field. In certain instances, an attempt has been made to standardize and state technically correct definitions, as in avoiding the term "spiral ramp" to describe a surface that is essentially a helicoid.

As described in Chapter II, the principal function of the main floor of a garage is the acceptance and delivery of vehicles. The features incorporated in the main floor of various garages are seldom the same and a great variety of designs that will provide efficient operation are possible.

The main floor is generally located at ground level but may be one story above or below the street. Garages with storage floors both above and below the ground, show no advantage in the below-ground location. But where there is demand for stores, restaurants and other places of business, it may be desirable to use the ground floor for these purposes because of the greater revenue involved. In these cases, customers may be asked to drive up or down a ramp for a distance of one floor to reach the acceptance and delivery area. In such cases observed in this study, the financial advantages gained did not offset the operational disadvantages. Customers are often required to stop on approach ramps, with the result that cars may roll down the ramps or be stalled by excitable drivers. In addition, the customers must make a return journey by elevator or stairs to the street level before they can continue on their original business.

ENTRANCES AND EXITS

The interchange of vehicles between the garage and adjacent streets is of major interest to both garage proprietors and to mu-



FIGURE 17. Garage Entrance at Which Left Turns Have Been Prohibited by Municipal Authorities Because of Interference With Street Traffic

nicipal traffic authorities. Openings, by location and number, must provide direct access to all major traffic streams in conformance with local regulations. Entrances must present an attractive appearance to prospective customers and exits must provide safe crossings of pedestrian and vehicle streams.

In conjunction with parking surveys to determine the size and location of proposed garages, attention should be given to the street system and traffic flows affected by the entrances and exits of the new facility. Anticipated changes in the traffic pattern from changes in the one-way street system, construction of expressways or bridges, or the development of new suburbs, should be evaluated and given proper attention in orienting the entrances and exits. Additional turning movements induced at nearby intersections by the construction of a garage should be carefully considered. It will always be profitable, and sometimes legally required, to consult the local traffic authority on the location of entrances and exits.

It is generally accepted that entrances and exits should be as far as possible from street intersections. The slow movement in and out of restricted openings and across pedestrian sidewalks should be removed from the normal congestion of street intersections. Again, the signalization of nearby intersections offers a definite limitation to movement in and out of garages. In several garages observed, cars could not leave the exits during rush periods while the nearby light was green because of moving traffic; nor while the light was red because of other cars waiting at the light. Some garages have an employee deputized so he may step into the street and control traffic to allow cars to leave the garage. Others depend on one or more municipal police to handle such traffic, a process difficult to justify in terms of expense to the city.

In two cases observed in this study, city traffic authorities found it necessary to prohibit left turns into and out of large parking garages, because of the interference to other traffic. An example is shown in Figure 17. At this garage, round-the-block movements are required from an appreciable number of patrons in order to approach from the prescribed direction. In such instances, structural changes and the removal of adjacent buildings may be required for free movement in and out of the garage.

Entrances and exits should be large enough to admit cars easily without damage. Furthermore, the total opening should appear attractive and avoid an impression of a "hole-in-the-wall." For this purpose, double or triple lane entrances are desirable, with a total width of about twelve feet per lane. Exits should allow ample sight distance at sidewalk crossings and may be protected by an automatic bell or other device to warn pedestrians whenever cars leave the garage. In enclosed-type garages, doors can be closed during the winter.

RESERVOIR SPACE

The reservoir or magazine space for incoming and outgoing cars is the most important area in a garage. Poor layout of ramps and stalls can be overcome by skillful driving, and general "slow" design by employment of additional attendants. Elevators and cashier's cages can be modernized or expanded, but inadequate reservoir space is almost always a fixed liability built into the garage. Further, the lack of reservoir space breaks down the garage operation during the peaks of highest demand. Customers are turned away, adjacent streets congested.

A reservoir space absorbs peak inbound cars that exceed the rate at which attendants can store them—of greatest importance in attendant-parking garages. Customer-parkers drive directly to storage floors, and pause briefly on the main floor, if at all. Customer-parking requires basically different area from attendant parking. The type of operation should therefore be selected before reservoir space is laid out.

As a customer enters the reservoir space, he is issued a parking check, which requires about thirty seconds, depending on the type of ticket used.¹ He must also be allowed time to unload passengers and bundles, a process more indefinite in time. For a driver alone, the unloading time may be zero, for he will get out of the car while the parking check is being issued. For several passengers with articles to be removed from the trunk, the unloading

¹In one garage using a three-part ticket, on which the floor-man stamped the time and wrote down the state and number of registration, the time required per car consistently averaged 30 seconds, for over twenty-five observations.

may take a minute or more. Thus each car must stand in the reservoir from thirty to ninety seconds before an attendant can drive it away. In a busy garage with a large reservoir space, this delay is not significant; in a garage with an inadequate reservoir, the delay may hold up several attendants and keep customers waiting outside.

The number of attendants, the time needed to remove each car to the storage floors, and the size of reservoir space are closely related. The rate of storage varies directly with the number of attendants and inversely with the time to store each car. Thus, the rate of storage per hour equals the number of attendants times sixty, divided by the time in minutes required for an attendant to make a round trip, driving a car to the storage floor and returning by elevator or stairs.

On an average, the rate of storage must equal or exceed the rate of car-arrival during the peak period. Reservoir space takes care of spurts that exceed the average arrival-rate and of accumulated cars when attendants fall below their storing average. An inadequate reservoir can be partly compensated for by additional attendants, while a large reservoir will allow the employment of fewer attendants. But these adjustments of personnel may prove uneconomical. The problem is to determine the proper-size reservoir for any probable rate of arrival and storage.

Size Required

No general rule for the required capacity of reservoir space is known. A size of seven to ten spaces for each hundred of car-capacity is suggested by the American Automobile Association.⁹ Another authority suggests that a reservoir space for ten to twelve cars is sufficient for a garage of *any* capacity. Neither of these bases is entirely correct because reservoir requirements are based on *rates of movement*. A garage with high inbound rates and short-term parking will require a larger reservoir than a garage of equal capacity with a rate of flow that is evenly distributed and low, regardless of capacity.

⁹*Parking Manual*, Traffic Engineering and Safety Department, American Automobile Association, Washington, D.C., 1946. p. 134.

In any discussion based on observations of existing garages, distinction must be made between inadequate reservoir space and inadequate capacity. Cars waiting outside an already-filled garage indicate the need for more storage space; waiting outside a partly filled garage, they indicate a lack of reservoir space or a slow rate of storage, or both. When a garage is filled, the reservoir space should also be full, since this area is as valuable and usable for parking as any other. In such cases, the capacity of the garage does not satisfy the demand, and no amount of area within the garage designated as reservoir would be adequate.

Applying the Theory of Probability

If the average rate of arrival at a garage is known, the probability with which a given number will arrive in any period can be computed. Applying the theory of probability to reservoir space computations, it is possible to compute the size and occurrence of short surges of demand, provided the average flow during peaks is known. The difference between these surges and the average rate of storage is equal to the accumulation of vehicles; that is, the reservoir space required. It is first necessary to consider the ranges of incoming flows and storage rates. In the garages observed in this study, the maximum hourly inbound flow was 320 cars, and in most cases did not exceed 150 cars. The average time required for an attendant to store a car was three to six minutes (see p. 57), and the number of attendants in larger garages ranged from five to twenty-five. It is necessary to determine roughly these values for any particular garage in order to apply the theory outlined below. An assumption which simplifies calculations and which represents good operating practice is that the rate of storage must equal the average rate of arrival during the peak hour.

Assume that cars are arriving at a parking garage at a rate of 100 an hour, and that attendants store them at this rate. Thus, a car arrives every thirty-six seconds, as shown in the first two columns of Table III. From tabulations of the values of Poisson's series, the maximum number of cars arriving in a given period of time can be obtained, provided that the average number of ar-

Table III

ACCUMULATION OF VEHICLES IN A RESERVOIR SPACE

<i>At the End of</i>	<i>Average No. Arriving</i>	<i>Maximum Arriving 99% of the time</i>	<i>No. Handled by Attendants</i>	<i>Accumulation</i>
36 seconds	1	5	1	4
72 "	2	7	2	5
108 "	3	9	3	6
144 "	4	10	4	6
180 "	5	12	5	7
216 "	6	13	6	7
252 "	7	15	7	8
288 "	8	16	8	8
324 "	9	18	9	9
360 "	10	19	10	9

rivals (Column 2) and the allowable probability of failure are specified. (There is no upper limit to the number of arriving cars if no failure is allowed). A probability of failure of 1 percent has been assumed in this case. The values shown in Column 3 are those taken from the Poisson tables.⁸ The fourth column shows the number handled by the attendants in successive periods which, in this case, equals the average number arriving. The fifth column shows the accumulation possible if the maximum number of cars arrives, and is equal to the difference between Column 3 and Column 5. Further consideration reveals that the length of the time interval does not affect the values obtained, so that the same tabulation may be used for all rates of incoming flow. Figure 18 shows the values obtained from such calculations for rates of storage equal to 0.9, 0.95, 1.0, 1.05, and 1.1 times the rate of arrivals. From these curves it is possible to obtain the capacity of reservoir space required for any rate of arrival. Completing the above example, it is found that for equal rates of arrival and storage of 100 cars an hour, reservoir space is required for twenty-five cars.

The 1 percent probability of failure is significant. Applied to this problem, it means that the reservoir space will be overloaded

⁸*Poisson's Exponential Binomial Limit*, E. C. Molina, D. Van-Nostrand Company, Inc., 1942.

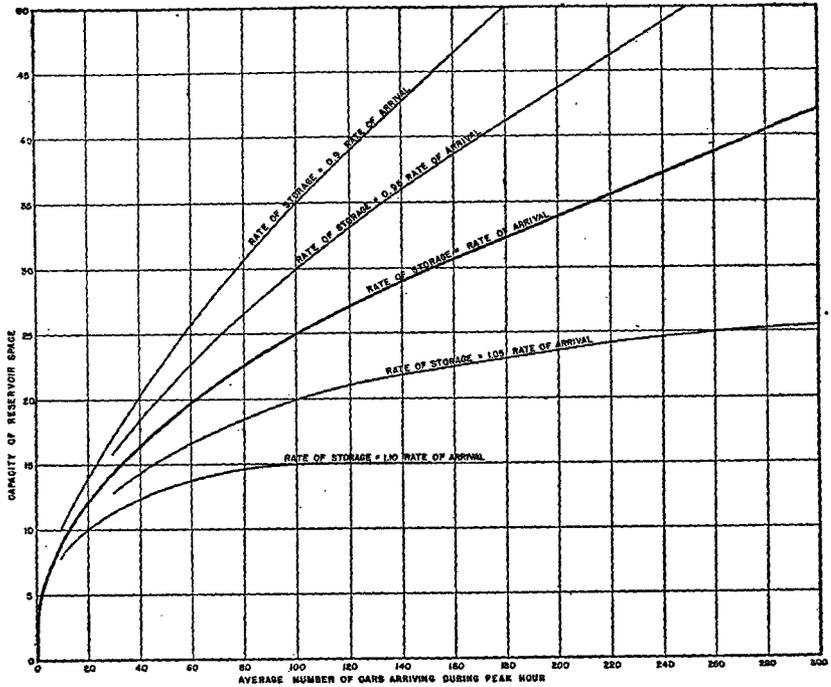


FIGURE 18. Reservoir Space Required for Various Vehicle Arrival Rates, If Overloaded Less than 1% of Time

less than 1 percent of the time. Similar graphs may be drawn for any percentage of overload. The use of 1 percent overload is recommended, because experience proves the need for large reservoir spaces. In one specific example, a garage with a peak flow of 320 cars an hour has a reservoir capacity of forty-four cars. The operation results in neither waste of space or attendants' time. This checks closely with Figure 18.

The effect of a shortage of attendants is well-illustrated by Figure 18. For a nominal rate of flow of 120 vehicles an hour and a storage-time of four minutes a car, the reservoir space required for seven attendants (approximately $0.9 \text{ flow} \frac{7 \times 60}{4} = 105$ cars per hour) is thirty-seven car spaces; for eight attendants (equal flow $\frac{8 \times 60}{4} = 120$ cars per hour) is twenty-seven car spaces; and for

nine attendants (approximately 1.1 flow $\frac{9 \times 60}{4} = 135$ cars per hour) is fifteen car spaces. Thus, if a storage rate equal to the arrival rate is considered normal, a deficiency of one attendant would require an additional reservoir space for ten cars, while an excess of one attendant would require twelve fewer car spaces in the reservoir.

Flattening of the curves representing a rate of storage 1.1 times the rate of arrival indicates the condition where a constant-sized reservoir space may be used for all rates of flow. This condition, however, may require an excessive number of attendants, especially in peak periods. Attendants, of course, must be paid for off-peak periods. In addition, the unloading time of customers will affect the flows in reservoir spaces of this size.

Rule for Capacity of Reservoir Space

The capacity of reservoir space required for a particular garage may be determined from Figure 18. The inbound flow during the peak-hour may be estimated from parking surveys and a comparison with similar garages, as shown in Chapter III. It is good practice to allow overloading of the reservoir not more than 1 percent of the time and to employ sufficient attendants so that the rate of storage equals the rate of arrival during the peak hour.

Thus, in Figure 18, beginning at the appropriate figure for the Average Number of Cars Arriving During Peak Hour, trace a line vertically to the point where it intersects the curve Rate of Storage = Rate of Arrival and from that point horizontally to the vertical scale which indicates the Capacity of Reservoir Space.

The high value of the ground-level area of a garage makes it attractive for other and more profitable uses, such as auto accessory stores, or other retail and service establishments. This is a real demand that may be highly profitable because of the assured steady flow of customers. The income from such uses may contribute materially to the financial success of the garage.

Such installations, however, have often been made at the expense of adequate reservoir space to the ultimate detriment of the entire garage operation. The best rule is to make the reser-

voir space as large as allowed by the size and shape of the land parcel, up to that shown by previous calculations, remembering it is an open area, convertible to other uses when necessary. But it is seldom practicable to convert part of a commercial area to reservoir space.

Reservoir Layout and Appearance

The usual arrangement of a reservoir space is to provide lanes leading from the street-entrance to the ramp. As cars enter the garage, they are directed into successive lanes; drivers are asked to drive into the garage as far as possible, thus filling the reservoir space one lane at a time. As cars are ticketed and drivers leave, attendants move cars to storage floors, clearing each lane in turn. For a given size of reservoir, the turnover can be higher as the number of lanes is increased. Cars must enter and leave the reservoir through restricted openings at the garage entrance and ramp approach, and cannot use unlimited lanes because of turns required. Four lanes is the largest number in common use.

The appearance of the reservoir in an attendant-parking garage is important in attracting customers. It is almost the only part of the garage they ever see. It should be clean, well-drained, well-lighted, and should provide adequate paths for safe pedestrian movement.

The illumination should be designed so that customers can drive in from a brightly-lighted street and be able to see clearly. Spot-lamps and other sources of glare should be avoided, and indirect or diffuse lighting used where possible. Walls and ceilings should be light in color, with contrasting colors and patterns on columns or other obstructions. This requirement favors a brief stop on the main floor of customer-parking garages for issuance of identification tickets, so drivers may accustom their eyes to lower light levels before driving on the ramps.

Adequate space should be provided between lanes to allow customers to get out of cars without danger from other moving vehicles. Pedestrian walkways with curbs painted white may be raised four to six inches between lanes. Two conflicting requirements on the width between curbs are: (1) that the customer may

step directly from the car to the curb, and (2) that there be room to avoid scraping tires on the curb. A compromise may be reached with lanes about eight feet between curbs providing no turns are required. If no curbs are used, the lanes should be ten to twelve feet in width, depending upon the column arrangement.

A small number of legible and concise signs are required: (1) to direct incoming drivers to drive into the garage as far as possible; (2) to direct drivers to turn off the motor and leave keys in the car; and (3) to state parking rates.

An outbound reservoir is required for delivery of vehicles and for loading customers, passengers, and bundles. This space need not be as large as the inbound reservoir, but must have the feature of providing room for cars to pass each other, in order that one slow-loading or uncalled-for vehicle will not block all operations. Part of the inbound reservoir space is often used for peak outgoing movements.

Ramp Location

Ramp approaches should be oriented so as to lead directly from the reservoir space. This requirement is important, as it saves difficult and time-consuming movements. In one garage observed, the ramp entrance leading to floors below the street was displaced so it was necessary to drive to the second floor, back to the ground floor, and then down to the lower floors. In fairness, it should be said that this particular arrangement was not necessary when the garage was built, but was caused by the increased length and turning radii of modern cars.

In locating the ramp systems, demands of the main floor must be balanced against those of storage floors. For the main floor, it is desirable to have ramps as far from the entrance as possible to provide a maximum reservoir. Unusually-shaped land parcels and the unusual construction difficulties of certain types of ramp make it often necessary to place ramps in positions not best suited to other requirements. This is illustrated in a garage where the land parcel curves sharply at one end, thus providing an almost ideal shape for a circular ramp. In other cases, it has been possible to save floor space for parking by cantilevering the ramp

structure over an adjacent alley or building owned by the proprietors of the garage.

LOCATION OF INTERFLOOR DRIVER TRAVEL MEANS

Elevators, fire poles, stairs, and other means of interfloor driver-travel (discussed in Chapter VII) have their terminals on the main floor. Since the normal *paths* attendants take and their repeated trips to park and un-park can be predicted, including the cashier's office, the reservoir space and the interfloor driver-travel means, these facilities can and should be efficiently placed. A satisfactory means is to have the terminal of the interfloor driver-travel adjacent to the cashier's cage.

The principal movements of customers within an attendant-parking garage are concentrated on the main floor—travel from reservoir space to pedestrian exit, and from pedestrian entrance to cashier's office, thence to delivery point. In customer-parking

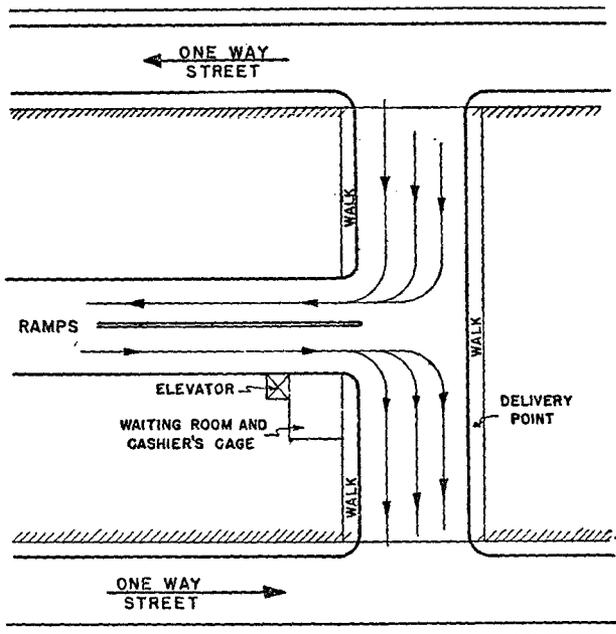


FIGURE 19a. Main Floor: Many Points of Conflict Between Cars and Pedestrians

garages, there is additional travel on the storage floors between parking stalls and elevators. It is characteristic of pedestrians in such cases to wander between cars and to take the shortest possible paths. To meet this difficulty, it is desirable to establish definite pedestrian paths in the layout of the garage, emphasizing arrows.

In one garage observed, the pedestrian paths crossed all lines of traffic movement, and were generally complex and hazardous. A simplified sketch of this layout is shown in Figure 19a. An alternative design is indicated in Figure 19b, in which pedestrians have direct access to the cashier's booth from both streets, with a minimum of reasons for crossing vehicle paths.

Another instance of hazardous pedestrian paths occurred in a garage where the acceptance point was on the second floor between the up and down ramps, with the stairway a few feet beyond the ramp. The natural path was to walk up and down the ramp rather than the stairs.

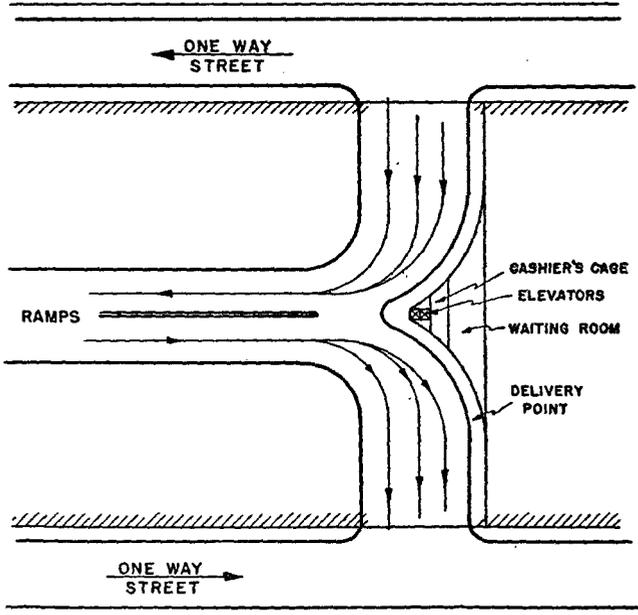


FIGURE 19b. Alternative Layout: Keeps Pedestrians Out of Vehicle Paths

The entrance for returning customers should be clearly marked on the outside of the garage to avoid their use of the vehicle lanes. Such marking of the entrances will gain their attention and lead them directly to the cashier's office and delivery point.

The cashier's cage, situated conveniently for both customers and attendants requires but small floor space and little equipment, containing only bookkeeping system for the location of cars and a cash register. Additional accounting for the garage should be done in other offices. As stated above, the cashier's cage should be located so that it is convenient to in-coming customers and to attendants making deliveries.

In designing large garages, the question of duplicate ramps, cashier's facilities, and other features must be analyzed. Except for garages of large ground-level area, such duplication is generally unwarranted. In the garages studied, instances were found where a second set of ramps or entrances was closed to avoid the confusion of cars travelling in different directions. As a general principle, the traffic capacity of entrances and ramps does not limit the rate of in-flow or out-flow. Duplicate cashier's cages or other control features confuse customers who do not return to the place they left their cars. Sufficient entrances and exits should be supplied for major traffic streams on adjacent streets, but additional ones are unwarranted.

SUMMARY

The main floor is the center of activity. Entrances and exits must be located to facilitate interchange of vehicles between the garage and the traffic on adjacent streets. The reservoir space in attendant-parking garages must be large enough to absorb peak flows that exceed the rate at which attendants can store cars. The cashier's cage, interfloor driver-travel means, and reservoir space are closely inter-related; they should provide short and direct travel paths for attendants. The outbound reservoir space must provide multiple delivery points and sufficient lanes to prevent blocking by undelivered or slow-loading cars. Customer-parking

garages require little reservoir space and are characterized by a dispersal of activity over the entire garage. This reduces the importance of the main floor.

LAYOUT OF STORAGE FLOORS

Storage levels of a garage are generally of the same shape and layout, excepting the roof, which is free of columns. Parking stalls and access aisles are basic units to be considered in the layout. To

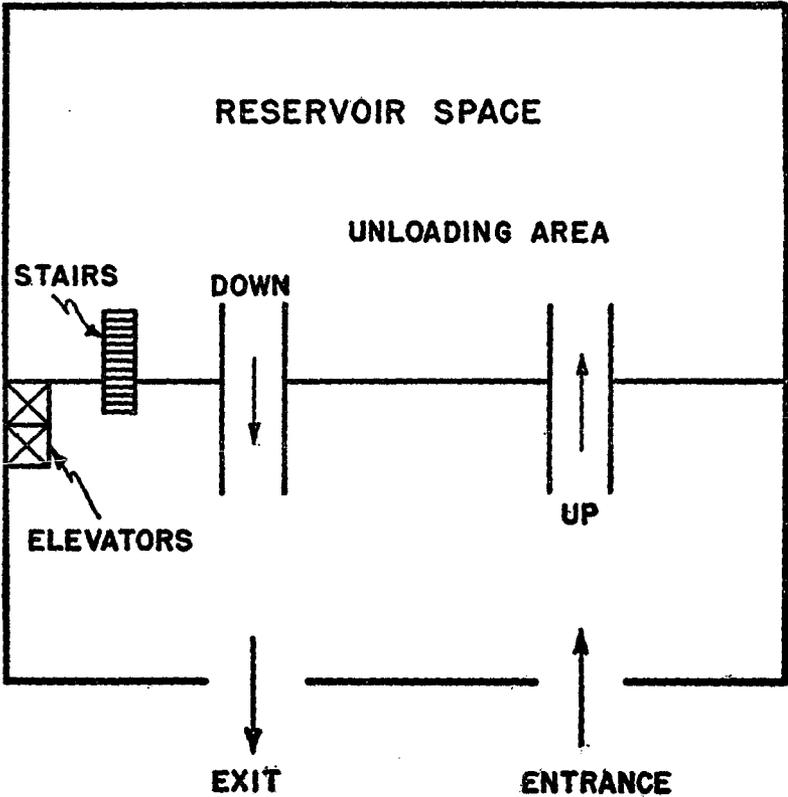


FIGURE 20. Main Floor: Invites Pedestrians to Travel on Vehicular Ramps Rather than Stairs

obtain as much storage capacity as possible, a maximum number of stalls should be placed on every floor. Conversely, an overcrowding that restricts necessary movement will decrease the

rate at which cars can be stored and delivered. That situation impairs efficiency of operation. A careful and flexible layout will do much to insure satisfied customers.

Stall, aisle, and ramp dimensions should be based on the number of cars to be parked therein. Dimensions can be determined for cars in use when stalls and ramps are built. But the anticipated life of a garage is at least thirty years—much longer than the life of cars. Designers do not care to predict car styles this far ahead. So the dimensions chosen must be based on *assumptions* as to future car design and expected use of the garage.

ERRONEOUS ASSUMPTIONS

Assumptions in the design of earlier garages have sometimes resulted in obsolescence. Among these are:

1. "Cars currently produced pretty well represent the desires of the motoring public and the ultimate in designers skill, and so it may be assumed that the over-all dimensions of cars will not change materially."

This assumption in one form or another has influenced the design of many garages. It leads to obsolescence and inflexibility that may seriously reduce capacity as car designs change. In some garages, where the stall-size is rigidly fixed by columns or other structural features, actual losses of from one-quarter to one-third capacity have been noted.

This type of assumption is stated in the February 1929 *Architectural Record*.¹ Car dimensions tabulated showed an average width of 5 feet, 9 inches, and a maximum of 6 feet, 1 inch; and the following conclusion was drawn as to stall width:

"Six feet, nine inches width per car is sufficient parking-width under average conditions. Width in excess of seven feet is extravagant except in parking garages having a very high turnover."

Widths of cars manufactured in 1940–1947 average 6 feet, four inches in width, with a maximum of six feet ten inches. Such cars cannot efficiently be parked in stalls of 1929's recommended dimensions. *The layout of parking garages must therefore be adaptable to changes in car dimensions.*

¹E. P. Goodrich, *et al*, op cit. p. 183.

2. "The greater length and width of the larger and more expensive cars can be discounted somewhat in designing garages, because of the much larger number of small cars produced and in use."

In some parking garages, however, most of the cars parked are of the "high price" class. Stall, aisle, and ramp dimensions must be based on the *kinds* of cars that *use* a garage, and not on the number of various sizes produced.

A brief survey as to the make and model of cars using present-day garages was made in two garages, one in a high-rent business district in New York City, the other in Washington, D.C. where shoppers primarily were served. Data are shown in Figure 21.

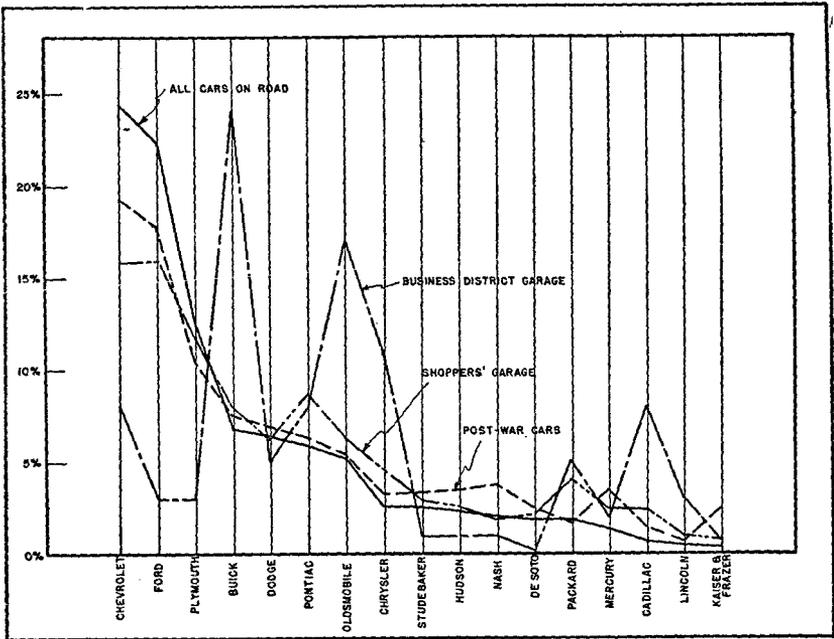


FIGURE 21. Distribution of Cars by Makes

The percentage of cars of each make using these garages is compared with the percentage of each make registered and the post-

war cars produced.² The distribution of cars by make in the Washington shopper's garage closely follows the distribution found in general on the road. In the New York business district garage, larger cars predominate.

Another aspect of use is that of the age of cars. Owners of relatively new cars are more likely than owners of old cars to park in garages because of service and protection. This is confirmed in Figure 22, which shows the percentages of pre-war and

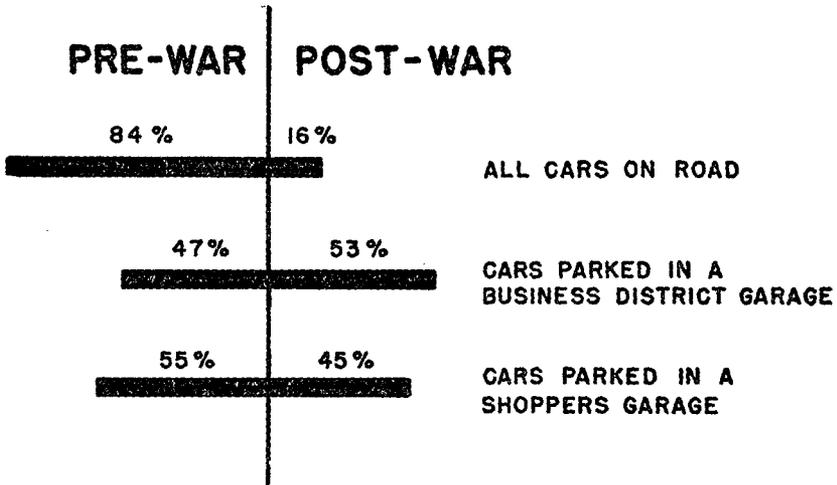


FIGURE 22. Distribution of Pre-War and Post-War Cars

post-war cars using the two garages, compared with cars on the road.

The most recent model cars must be given first consideration in designing a parking garage, and allowance must be made for the larger makes and models in greater proportion than they exist on the road, especially in high-rent downtown business areas.

² The percentage of cars of each make on the road was computed from data contained in "Automotive and Aviation Industries" March 15, 1947, which lists the total of each make and model registered on July 1, 1946, and the number of each make of car produced during the year 1946; and in "Ward's Automotive Reports," Nov. 29, 1947 which lists the number of each make of car produced during the first ten months of 1947.

3. "Large and small cars can be segregated in stalls of appropriate size." This assumption, made in determining the stall length for rows of double-parked cars—on the theory that a long and a short car could be parked tandem—often complicates the handling of cars. Sometimes the number of large cars exceeds the number of large stalls, thus encroaching on the aisles.

In garages observed, the attendants were not careful to segregate cars by size, and aisle space often was limited by extra-length cars placed tandem or on opposite sides of the aisles.

Although a few cars of extremely large or small dimensions may be stored in special-sized stalls, the majority of stalls should be of a standard size, large enough to accommodate all standard makes and models.

Future Trends

When automobile manufacturers are bringing out new "post-war" designs, and when rather radical changes are expected, it is especially dangerous to fix garage dimensions on current model cars. No material changes, except in ornamentation, have appeared in the majority of makes during 1941, 1942, 1946 and 1947, so the dimensions of *existing* cars are fairly uniform. The over-all width and length of the standard 1947 makes and models are shown in Table IV. Dimensions of stalls and aisles may be based on current model cars; the layout of the building should allow revision of stall and aisle dimensions to accommodate future changes.

Though assumption of definite design trends is dangerous, it is necessary to evaluate the trend of car dimensions and their effect on the future usefulness of a garage. Not much help can be obtained from automobile designers. They are notably close-mouthed about future trends, because style is an important selling factor in a competitive market, and predictions, difficult to make, are embarrassing if wrong.

One stabilizing factor in automobile sizes is the family garage. Many home garages now are too narrow for easy entrance, exit, and for passengers getting in and out of the car, and too short to close the garage doors with any room to spare. It might be ex-

Table IV
OVER-ALL LENGTHS AND WIDTHS OF STANDARD 1947 MODEL AUTOMOBILES*

Length			Width		No. Models This Length	No. Models This Length or Less	
	5'9"-6'0"	6'0"-6'3"	6'3"-6'6"	6'6"-6'9"			6'9"-7'0"
16'0"-16'3"	Studebaker Champion				1	1	
16'3"-16'6"		Plymouth Ford Chevrolet			3	4	
16'6"-16'9"		Nash 600			1	5	
16'9"-17'0"	Studebaker Commander	Kaiser Frazer Mercury	Oldsmobile 66	DESIGN VEHICLE	5	10	
17'0"-17'3"			Dodge Pontiac 25-27		2	12	
17'3"-17'6"		Nash Ambassador	DeSoto Buick 40 Chrysler C-38 Packard 2000-1-10-11		5	17	
17'6"-17'9"			Pontiac 26-28 Oldsmobile 76-78		Buick 50	3	20
17'9"-18'0"			Chrysler C-39 Packard 2003-6		Cadillac 61 Oldsmobile 98	4	24
DESIGN VEHICLE							
18'0"-18'3"			Lincoln		Buick 70	2	26
18'3"-18'6"				Cadillac 62	1	27	
18'6"-18'9"				Cadillac 60S	1	28	
18'9"-19'0"				Cadillac 75	1	29	
19'0"-19'3"							
19'3"-19'6"							
19'6"-19'9"			Chrysler C-40 Packard 2126		2	31	
No. Models of This Width	2	8	14	6	1		
No. Models of This Width or Less	2	10	24	30	31		

* The data from which this tabulation was made, as well as later computations on door openings and turning radii, were furnished through the courtesy of the engineering departments of the Chrysler, Ford, General Motors, Kaiser-Frazer, Nash, Packard, and Studebaker Corporations.

pected that automobile designers would consider this factor before radically enlarging car dimensions, in order to avoid consumer resistance.

The post-war design change of most interest in garage layout is the blending of body and fender lines. In some cars this effect is gained by narrowing wheelbase and fenders to meet body dimensions; in others, by widening the body to the full width of the fenders. The result is that doors are hinged almost at the outer-most point of the car, and the slight indentation between the front and rear fenders, which previously allowed more access for squeezing into the door opening, is no longer available. This design change is apparent on 1948 models that had appeared when this report was written. Many existing garages are now operating with absolute minimum clearances; so when cars of the new wide-body design exist in appreciable numbers, these garages may lose as much as one-third their capacity.

STALL LENGTH AND WIDTH

The length of parking stalls is determined solely by the length of the cars to be parked. In Table IV, the length of 1947 model cars appears for most models to be 18 feet or less. Those exceeding this dimension are the Lincoln, Cadillacs 62, 60S and 75, and the largest models of Buick, Chrysler, and Packard, the longest of which is 19 feet, 8 inches. Several different long-wheelbase models, not shown in the table, are manufactured for seven-passenger sedans and other special-purpose bodies, none of which is produced in appreciable quantity. Since it would be uneconomical to provide for the most extreme models, a stall length of eighteen feet would be adequate, with the few remaining longer models allowed to encroach on the aisle.

Parking-stall width depends on the over-all width of cars, the movement of cars entering and leaving, and the space required for drivers to get in and out of the doors. The over-all width of 1947 models averages 6 feet, 4 inches, the widest point usually at the rear fenders. The majority of cars do not exceed 6 feet, 6 inches. Exceptions are Cadillacs and the largest models of Buicks and Oldsmobiles. For movement in and out of stalls, a one-foot

clearance on each side is generally sufficient. That indicates a stall-width of about 7 feet, 6 inches.

However, a new limitation has arisen on the minimum widths of stalls, caused by the trend towards wider bodies, streamlined fenders, larger doors, and the hinging of doors closer to the outside of the car. Skilled drivers can park a car in a stall with only a few inches side clearance, but they cannot open the doors sufficiently to get out. The limitation is somewhat less critical for attendant than customer-parking, since the attendants are usually agile and do not mind squeezing through small openings. Customer-parkers cannot be expected to squeeze through narrow door openings or between dirty fenders. The movements of attendants in and out of cars is materially slower for restricted stall widths, thus increasing the handling time per car. This increased time of getting in and out of a car is difficult to measure because of the several movements involved. The time required for an attendant to stop a car, turn off the ignition, get out, and close the door, is about six seconds, if the car is in an open aisle or an adequate stall. In the most extreme case observed, in which the attendant had to climb through the window, the time required was over thirty seconds. Based on observation, it may be said that narrow stalls will require an additional five to ten seconds a car for the movement of the attendants.

Another factor requiring wider stalls for customer-parking is accuracy of placement. Attendants can place a car in the center of a stall, leaving nominal inter-car space to each side. This is not often the case with customer-parking, that tends to further decrease the distance available for door opening.

Measuring Stall Width

To check the normal door-opening widths, measurements were made on cars parked at the Yale Bowl for a football game. In this case, all cars are driven into place in double lines. Attendants direct them into place and ask drivers to park as close as possible to the next car. Although these conditions do not reflect actual parking practice in garages, an opportunity was offered to observe the movements of a large number of people getting out of cars

in a somewhat restricted space, and to correlate these movements with the actual distance available for opening the car doors. Observations were noted on the basis of "restriction of movement", and "no restriction of movement". Distances were measured between the bottom edge of the door opened and the limiting point on the adjacent car. Distances at which restricted movement was observed ranged from seventeen to twenty-five inches, with an average of twenty inches and a median of nineteen inches. For no restriction of movement, distances ranged from eighteen to forty-eight inches, with an average of thirty-one inches and median of thirty inches. From such a wide range of data, it is difficult to draw specific conclusions, but it would appear that a door-opening distance of twenty-four to thirty inches is desirable for customer parking. With current model cars, on which the door is placed at almost the widest point, this opening would require the same inter-car distance, or a stall width of 8 feet, 4 inches to 8 feet 10 inches.

Another approach to the determination of stall width for customer-parkers was tried in measuring the "natural spacing"; that is, the average stall-width used by customers parking in commercial parking lots without lane-markings or other restrictions. Averages for several different lots ranged from 8 feet to 8 feet, 6 inches, neglecting the larger openings left by careless parkers. The smaller widths used by customers in these lots may be due to an appreciation of the need for space, as opposed to the somewhat carnival spirit at a football game. This does not alter the conclusion that a minimum of twenty-four inches is required for customers to get in and out of cars without restriction of movement.

Stall-widths in attendant-parking lots range from seven to eight feet, depending on the type of operation. Operators of efficiently operated lots with a high turnover believed generally that eight foot stalls are adequate for attendant parking. Almost all expressed the opinion that the latest models, such as the 1948 Packard, might require even wider stalls.

For present-day cars, the minimum stall-widths allowable are 8 feet for attendant-parking and 8 feet 6 inches for customer-parking. An eight foot stall will allow inter-car distances ranging from 13 inches to 26 inches for 1947 model cars. An eight foot six inch stall will allow 19 to 32 inches.

ACCESS AISLES

Desirable dimensions for stalls may be taken, then, as eighteen feet in length and 8 feet or 8 feet, 6 inches in width. A basic area of 144 square feet for attendant-parking and 153 square feet for customer-parking is required for storage. Additional area to make stalls accessible to movement will depend on the direction and angle of parking. Other factors are the minimum turning radii and path of the moving vehicle, and the clearance between the moving vehicle and adjacent parked vehicles.

To make physical checks on minimum turning movements, a series of measurements were made with a car on concrete pavement moving at low speeds with the steering wheel in the fully-turned position. Although these conditions do not always obtain in parking, the results are indicative, as listed below:

1. The center of rotation lies on the line of the rear axle, and successive circles can be driven with little movement of this point.
2. The minimum turning radius of the inside rear wheel, together with the fixed dimensions of the car, is sufficient to determine the radius of all points, neglecting slip angle.
3. The minimum turning radius for right turns and left turns is generally different. This is a quality built into the automobile, and either may be larger. For example, in the 1942 Oldsmobile the turning radius of the outermost point of the front bumper was seven inches less for a right turn than for a left turn.
4. The minimum turning radius is less for backward movements than for forward movements. For the Oldsmobile, this difference amounted to about ten inches, measured at the front bumper. This difference may be accounted for by the slight

amount of play in the steering mechanism; the caster of the front wheels tends to straighten them on forward movements and to turn them more sharply on backward movements.

From these measurements it was concluded that the forward movement of a car, in the direction left or right for which the turning radius is maximum, should be used in computing the space necessary for turning movements. The small difference in turning radii for other movements will act as a factor of safety.

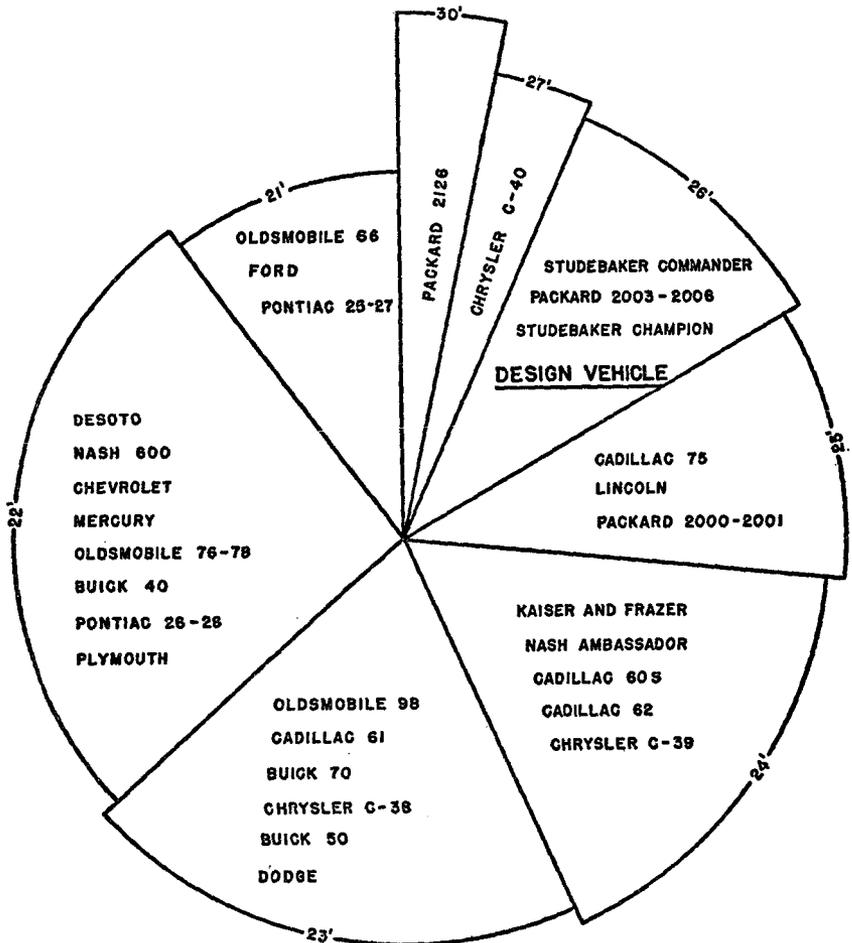


FIGURE 23. Minimum Turning Radius of Extreme Outside Point, Standard 1947 Model Automobiles

A "Design-Vehicle"

A questionnaire was sent to each major automobile manufacturer, concerning the minimum turning radii of 1947 models for forward and backward movements and for right and left turns. Although some manufacturers replied that the minimum turning radius was the same for backward and forward movement and

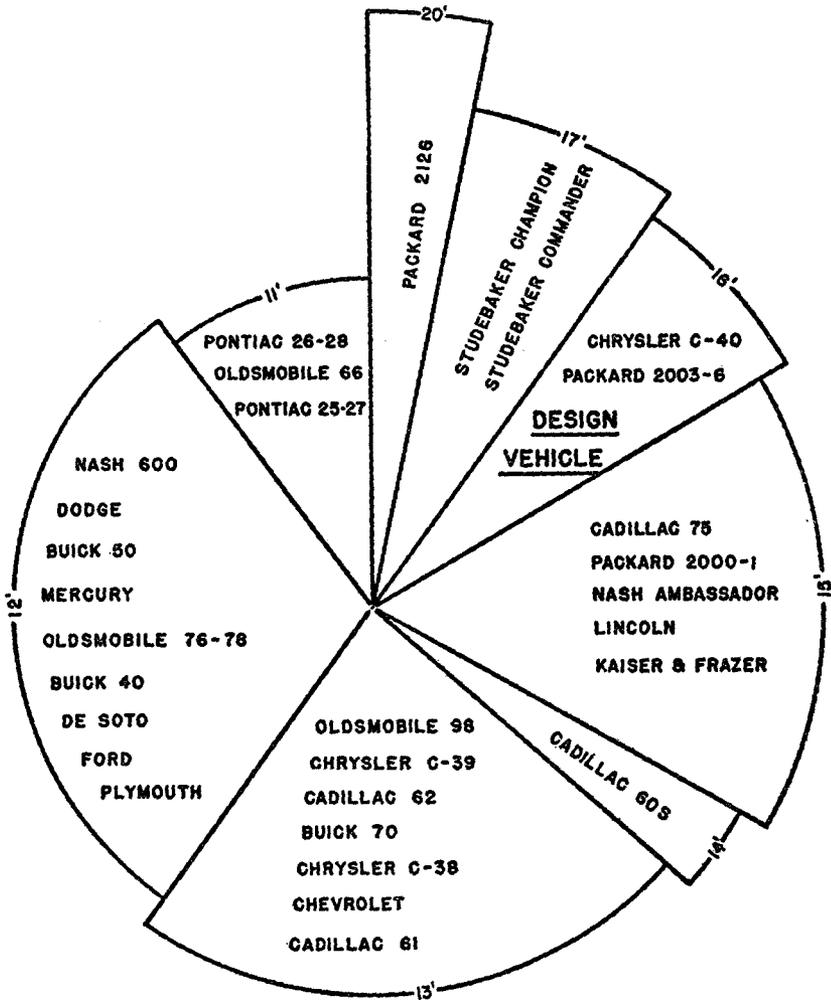


FIGURE 24. Minimum Turning Radius of Inside Rear Wheel, Standard 1947 Model Automobiles

for right and left turns, others submitted measurements that confirmed previous conclusions. Because of differences in methods of measurement and in tabulation by the various manufacturers, an exact comparison among all cars could not be made.

The two car-turning measurements of most importance in garage-design are the radius of the outside point (the front bumper) and the radius of the inside rear wheel. The relative values of these radii for 1947 cars are shown in Figures 23 and 24 respectively. The range of radii for the outside point is twenty-one

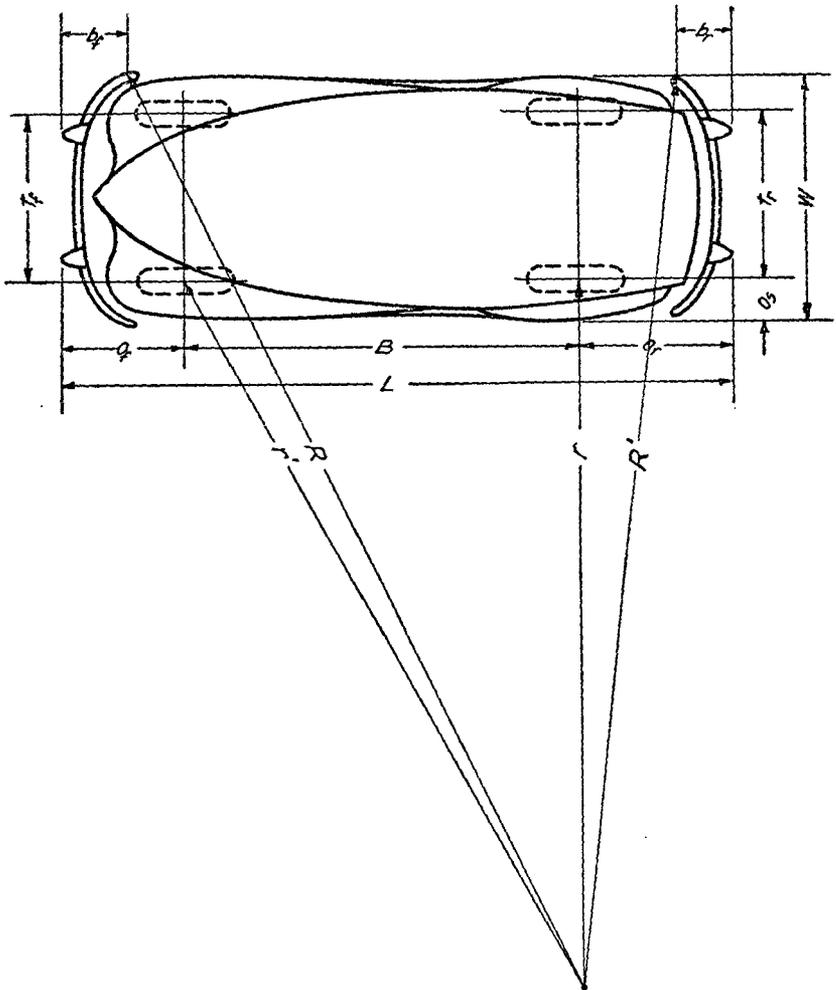


FIGURE 25. Vehicle Dimensions Necessary for Computing Turning Movements

to thirty feet, but the top of the range is perhaps not specially significant, since only two models have radii greater than twenty-six feet. The range of inside rear-wheel radii is eleven to twenty feet, with only one model over seventeen feet.

From these data on lengths, widths, and turning radii, dimensions of a "design vehicle" have been selected, and will be used in subsequent computations. These dimensions, listed below with symbols used in computations, are illustrated in Figure 25.

<i>Symbol</i>	<i>Dimension</i>	<i>Value for Design Vehicle</i>
L	Over-all Length	216"
W	Over-all Width	76"
B	Wheel Base	127"
O _f	Front Overhang (front axle to bumper)	36"
O _r	Rear Overhang (rear axle to bumper)	53"
O _s	Side Overhang (center of rear tire to fender)	8"
t _r	Rear Tread (center to center of tires)	60"
t _f	Front Tread (center to center of tires)	58"
r	Minimum Turning Radius—inside rear wheel	197"
r'	—inside front wheel	238"
R	—outside point, front bumper	303"
R'	—outside point, rear bumper	262"
b _f	Bumper Depth, from maximum turning point, front	12"
b _r	Bumper Depth, from maximum turning point, rear	8"

For subsequent computations, the following symbols will also be used:

S = Stall Width.

I = Inter-car distance = S - W.

c = Clearance between cars, as one moves into or out of stall.

θ = Angle of parking measured from a line parallel to the aisle.

It will be noted that the design-vehicle is not an "average" car, but one with dimensions equal to or greater than those of the majority of cars. Individual dimensions of extremely large models will exceed those of the design vehicle, but it is generally true that any standard make of car can be parked or driven in the same space as is required for the design vehicle.

Direction and Angle of Parking

Cars may be parked with rear end towards the aisle or front end towards the aisle. In this book, the term, drive-in parking, means rear end towards the aisle, back-in parking, front end towards the aisle. Customer-parkers generally prefer drive-in stalls, because they are more familiar with this type; and many drivers, especially women, do not like to back into restricted spaces—a real disadvantage for customer-parking garages. Four large garages employing back-in customer-parking were observed in this study. In each case, a floor attendant was available to guide incoming drivers, and the system appeared to work satisfactorily. A few new patrons unaccustomed to backing into stalls encountered difficulties, but regular customers required no guidance at all. Attendants apparently have no difficulty with back-in stalls. Admittedly, the parking maneuver is faster in a drive-in stall, but the unparking maneuver is slower, and more likely to produce collisions. A time comparison between the two systems could not be drawn, because *no garages were found which use drive-in parking*, except in a few special stalls. Garage-operators favor back-in parking because of the smaller aisle widths required, as shown in a later paragraph.

Formulas are derived in Appendix 1 for the aisle width required for parking at an angle θ with curb or wall. Certain assumptions made in these derivations do not always hold for actual parking maneuvers; hence the numerical values computed from these formulas cannot be taken as absolute measurements, but only for comparison of the aisle dimensions and area required for different types of parking.

The formulas derived for the aisle-width required to maneuver into or out of a stall in one pass, are:

(1) For drive-in stalls at angles of parking less than the critical parking angle.⁸ (See Figure 26).

⁸ The critical parking angle is defined as the angle at which the aisle width required for parking (or unparking) car to clear the car in the stall on the left is equal to the aisle width required to clear the car in the stall on the right. This angle is given by the expression

$$\theta' = \cot^{-1} \frac{\sqrt{R^2 - (r + t_r + O_s + i - c)^2} + \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}}{2S}$$

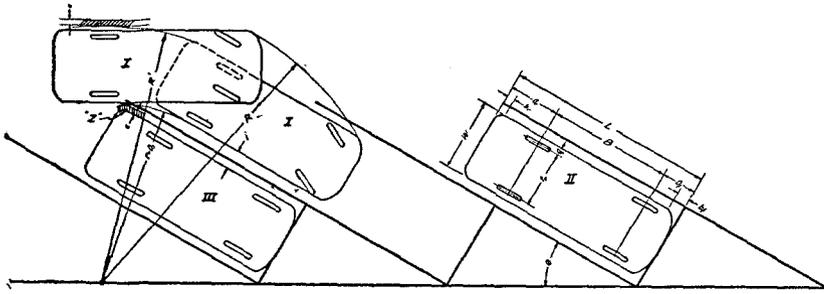


FIGURE 26. Drive-In Stall at Angle Less Than Critical Parking Angle. Movement is Limited by Car in Stall to Right

$$\text{Aisle width} = R' + c - \sin \theta (b_r + \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}) - \cos \theta (r + t_r + O_s - S)$$

(2) For drive-in stalls at angles of parking greater than the critical parking angle: (See Figure 27).

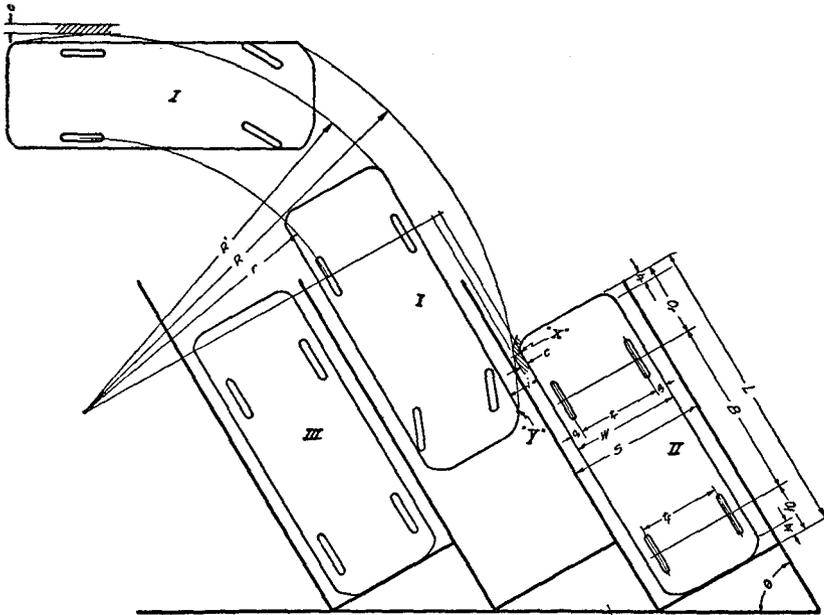


FIGURE 27. Drive-In Stall at Angle Greater Than Critical Parking Angle. Movement is Limited by Car in Stall to Left

$$\text{Aisle width} = R' + c - \sin \theta (b_r - \sqrt{R^2 - (r + t_r + O_s + i - c)^2}) - \cos \theta (r + t_r + O_s + S)$$

(3) For back-in stalls (See Figure 28).

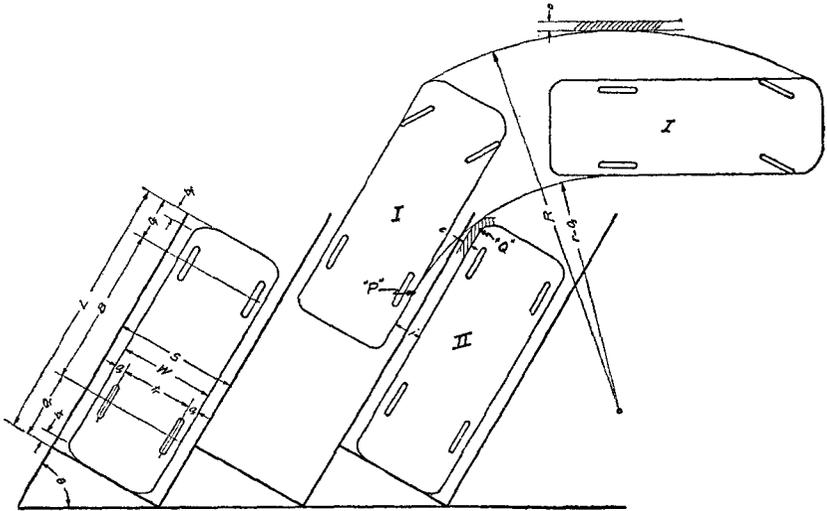


FIGURE 28. Back-In Stall

$$\text{Aisle width} = R + c - \sin \theta (b_f + \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}) - \cos \theta (r + t_r + O_s - S)$$

The distance from the wall or curb to the outside point on the rear bumper, measured perpendicular to the aisle, for any angle of parking is given by the formula:

$$\text{Stall depth} = L \sin \theta + W \cos \theta$$

A stall of width S at an angle θ will occupy a distance parallel to aisle equal to $\frac{S}{\sin \theta}$

For storage-floor layouts in which a single row of cars is parked on each side of the aisle, the area required per car is equal to one-half the aisle width plus the stall depth, multiplied by the width of the stall measured parallel with the aisle.

The above formulas have been evaluated for parking angles of 30° , 45° , 60° , and 90° , for a minimum clearance between cars of six inches and for varying stalls widths. Results are shown in Table V and Figure 29. From a study of these values, it may be

Table V

STALL AND AISLE DIMENSIONS AND AREA REQUIRED FOR VARIOUS ANGLES
AND DIRECTIONS OF PARKING WITH SIX INCH CLEARANCE

Stall	Dimension	Angle of Parking			
		30°	45°	60°	90°
7'6" Drive In	Aisle Width	86"	104"	197"	391"
	Stall Depth	174"	206"	226"	216"
	Stall Width	180"	127"	104"	90"
	Area (Stall plus ½ aisle)	271 sq. ft.	228 sq. ft.	234 sq. ft.	256 sq. ft.
(Critical parking angle 44° 13')					
7'6" Back In	Aisle Width	125"	139"	166"	243"
	Stall Depth	174"	206"	226"	216"
	Stall Width	180"	127"	104"	90"
	Area (Stall plus ½ aisle)	295 sq. ft.	243 sq. ft.	223 sq. ft.	211 sq. ft.
8'0" Drive In	Aisle Width	82"	93"	183"	378"
	Stall Depth	174"	206"	226"	216"
	Stall Width	192"	136"	111"	96"
	Area (Stall plus ½ aisle)	286 sq. ft.	239 sq. ft.	244 sq. ft.	270 sq. ft.
(Critical parking angle 45° 27')					
8'0" Back In	Aisle Width	121"	132"	152"	228"
	Stall Depth	174"	206"	226"	216"
	Stall Width	192"	136"	111"	96"
	Area (Stall plus ½ aisle)	313 sq. ft.	257 sq. ft.	232 sq. ft.	220 sq. ft.
8'6" Drive In	Aisle Width	80"	87"	167"	353"
	Stall Depth	174"	206"	226"	216"
	Stall Width	204"	144"	118"	102"
	Area (Stall plus ½ aisle)	303 sq. ft.	249 sq. ft.	253 sq. ft.	282 sq. ft.
(Critical parking angle 46° 9')					
8'6" Back In	Aisle Width	120"	125"	144"	212"
	Stall Depth	174"	206"	226"	216"
	Stall Width	204"	144"	118"	102"
	Area (Stall plus ½ aisle)	332 sq. ft.	268 sq. ft.	244 sq. ft.	228 sq. ft.

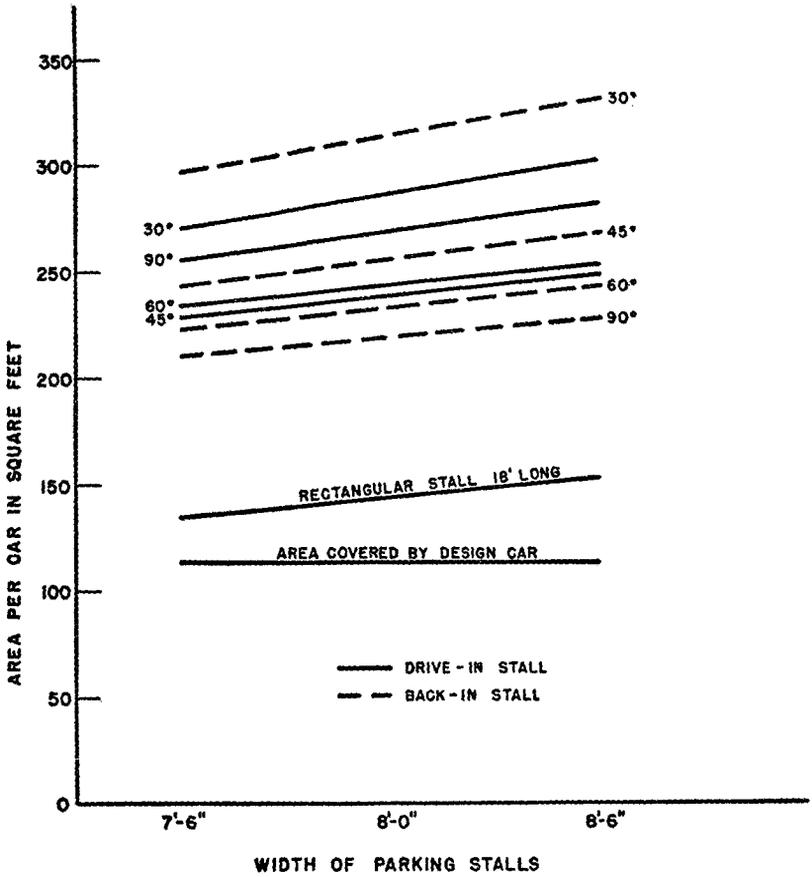


FIGURE 29. Area Per Stall Plus One-Half Aisle Required for Parking at Various Angles with Six Inch Clearance of Moving Vehicle

seen that drive-in stalls require less area for 30° and 45° parking angles, and that back-in stalls require less area for 60° and 90° parking angles.

The least area per car is required for 90° back-in parking. For the design vehicle parking in this type of stall, and with a six-inch clearance between vehicles, an aisle nineteen feet wide is required for eight-foot stalls and an aisle seventeen feet, eight inches wide is required for eight feet six inches stalls. These figures, however, are based on strict assumptions, such as no side-slippage of wheels,

and instantaneous full-turning of the steering wheel, that do not obtain in practice. They do, however, represent *minimum* aisle-widths for parking or un-parking the design-car in one movement.

Minimum Area

Stall-widths and aisle-widths are inter-related by virtue of the fact that wider stalls allow the turning movement to be started or ended deeper in the stall, so that less turning space, and hence width, is required in the aisle. In other words, when more area is provided in the stalls, less is required in the aisles, and vice versa. There is a certain combination of aisle and stall dimensions that will result in a minimum area per car.

For 90° back-in-parking, this minimum area may be found by substituting design car dimensions and evaluating the formula

$$\text{Area} = S \left[L + R + c - \frac{b_f - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}}{2} \right]$$

For the design vehicle, and a clearance of six inches, the area in square feet may be found from the expression

$$\begin{aligned} \text{Area} &= \frac{(76 + i) [216 + \frac{1}{2} (303 + 6 - 12 - \sqrt{(197 - 8)^2 - (197 - 8 - i + 6)^2})]}{144} \\ &= \frac{(76 + i) [729 - \sqrt{(189)^2 - (195 - i)^2}]}{288} \end{aligned}$$

By calculus, rejecting imaginary and negative roots, it is found that the minimum area per car occurs when the inter-car space "i" is equal to eight inches, or a stall width of eighty-four inches. Since this is less than is required to open the doors, the theoretical minimum area cannot be used.

Minimum Time and Aisle Width

The various combinations of stall and aisle widths can be assessed on the basis of time consumed in parking and unparking. Time-motion studies were made of parking movements in 90° back-in stalls for a rather wide range of stall and aisle widths. A complete

array of dimensions could not be obtained because some of the desired comparisons of dimensions were repeated in several garages, and others were not found at all. Results obtained in this study are shown in Table VI. They indicate the time in seconds

Table VI

TIME OF PARKING MANEUVER, IN SECONDS, FOR
VARIOUS STALL AND AISLE WIDTHS

Stall / Aisle Width / Width	14'	15'	16'	17'	18'	19'	20'
7' - 0"				a28	a17		c43
7' - 6"				a17			
8' - 0"	a38			c46			a14
8' - 6"							
9' +							c26

a—Attendant Parking
c—Customer Parking

required to back from aisles of various widths into stalls of various widths, measured from the end of a forward movement in the aisles to a complete stop in the stall. Stall widths shown are the nominal stall-widths between columns; the aisle-widths were roughly averaged by measuring the bumper-to-bumper-distance between cars on each side of the aisle which were protruding enough to limit the aisle space.

Although the table is not complete enough to be conclusive in detail, it does prove that a *significant reduction in time required for parking can be obtained by allowing adequate space for movement*. The dimensions of eight feet stall-width and twenty feet aisle-width provide for parking in a reasonably short time by attendants. Customer-parkers are slower, but they gain a time-advantage from more liberal stall and aisle dimensions.

Aisle Widths

In this analysis, aisle-widths have been considered on the basis of minimum clearance between vehicles and on precise car-movements not to be expected from average drivers. Additional aisle-

width is necessary to permit freedom and efficiency of movement and to allow for changes in car dimensions. Extra space allowed is limited by the economic consideration of keeping the total area required per vehicle to a minimum.

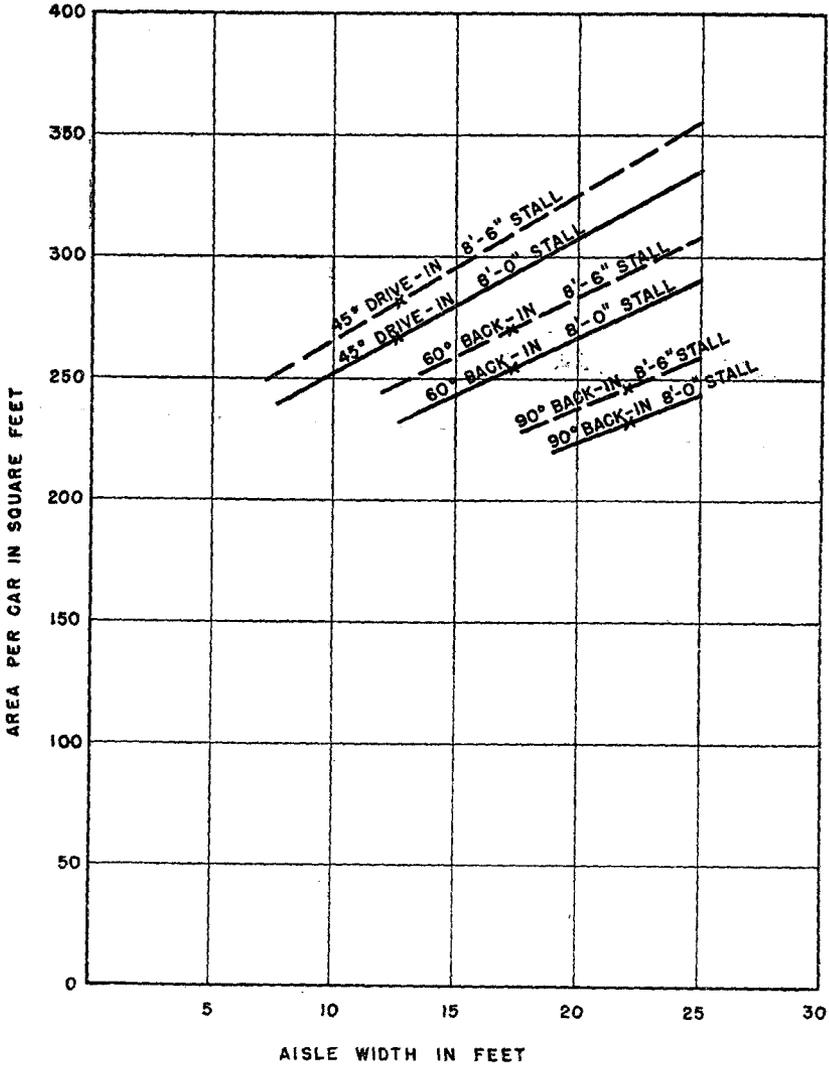


FIGURE 30. Area Per Stall Plus One-Half Aisle for Various Types of Parking Stalls and Different Aisle Widths. Starred Points Indicate Recommended Aisle Widths

Figure 30 shows the area required per car for different aisle-widths and for eight foot and eight feet, six inches stalls at 45°, 60°, and 90° angles. The lower point on each line indicates the minimum aisle-width required by the turning characteristics of the design vehicle, with a clearance of six inches. Starred points indicate the minimum aisle-width recommended for each type of parking (see also Table VII). Extra aisle-widths ranging from three feet to five feet, five inches are allowed, depending on the angle of parking. In each case, a greater safety factor is allowed for the wider stalls, because this type is intended for customer-parking.

The smaller area required for 90° stalls is again apparent in this figure. It may be noted that a 90° stall with three feet of extra aisle-space requires less area than an angle stall with no extra aisle space. In addition, it is believed that extra aisle-space must be allowed for angle parking because fenders are exposed to damage from moving vehicles, whereas only bumpers front upon the aisle in 90° parking.

UNIT PARKING DEPTH

In fitting parking-stalls and access-aisles to the dimensions and shapes of land parcels, it is convenient to use the width of an aisle plus the length of a stall on each side of it as a unit of measure. This may be called the Unit Parking Depth, and has a particular value for each angle of parking. Values derived from the recommended stall and aisle dimensions are shown in Table VII.

The use of these values may be illustrated as follows. Suppose a parking lot 175 feet by 200 feet is to be laid out for 90° stalls. Dividing each of the dimensions by the Unit Parking Depth of fifty-eight feet, it will be seen that three aisles can be placed across the 175 foot dimension, with little waste space. But the 200-foot dimension does not allow an even number of aisles. Hence, the aisles should be placed parallel to the long dimension of the lot.

The column in Table VII, headed "Number of Stalls in Distance D," may likewise be used to compute the number of cars that can be parked in a given area. The same information is shown graphically in Figure 31.

Table VII
RECOMMENDED STALL AND AISLE DIMENSIONS

Angle of Parking	Direction of Parking	Width of Stall	Depth of Stall Perpendicular to Aisle	Width of Aisle	Unit Parking Depth	Width of Stall Parallel to Aisle	Number of Stalls in Distance D	Area Per Car
90°	Back-In	8'0"	18'0"	22'0"	58'0"	8'0"	$\frac{D}{8}$	232 sq. ft.
60°	Back-In	8'0"	18'0"	17'4"	55'0"	9'3"	$\frac{D-11}{9.25}$	254 sq. ft.
45°	Drive-In	8'0"	17'2"	12'8"	47'0"	11'4"	$\frac{D-17}{11.3}$	266 sq. ft.
90°	Back-In	8'6"	18'0"	22'0"	58'0"	8'6"	$\frac{D}{8.5}$	247 sq. ft.
60°	Back-In	8'6"	18'10"	18'4"	55'0"	9'10"	$\frac{D-11}{9.8}$	270 sq. ft.
45°	Drive-In	8'6"	17'2"	12'8"	47'0"	12'0"	$\frac{D-17}{12}$	282 sq. ft.

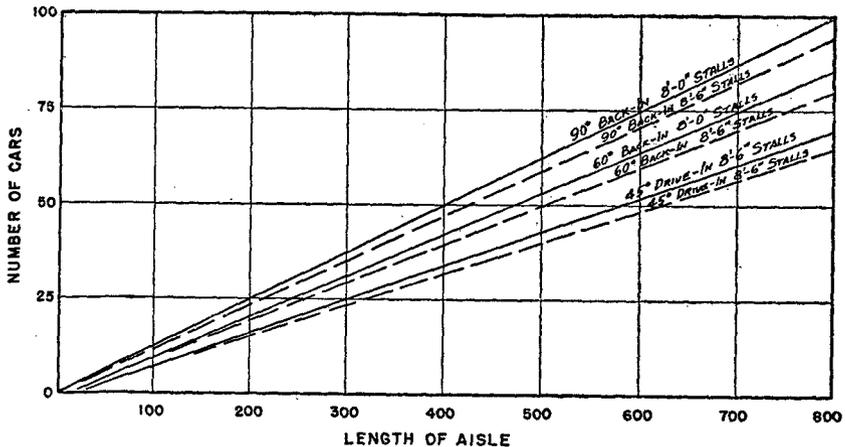


FIGURE 31. Number of Cars Which Can be Stored in a Given Length of Aisle with Various Types of Parking Stalls

For the 175 foot x 200 foot lot in the example above, it may be found from Figure 31 that twenty-five cars can be parked in eight foot stalls on the long dimension: a total of 150 cars in the lot, from which reservoir space and cross aisles must be deducted.

In garage design, column-widths must be added to the Unit Parking Depth or to stall-widths, depending upon the column arrangement.

OTHER CONSIDERATIONS IN FLOOR LAYOUTS

Parking at right angles to the aisles is the most common practice. There are several practical advantages, including the fact that rectangular stalls can be better fitted into buildings between columns and into corners.

Right-angle parking, moreover, allows the access-aisle to be used for two-way movements. Cars can be un-parked to either right or left, so they may return to the ramp along the same aisle and shortest travel path. On the other hand, cars parked in angle-parking stalls must be un-parked and continue along the aisle in the original direction, which requires that the aisles be continuous throughout the floor.

In garage layouts having the ramp system at one end of the building, it is economical of space and most convenient to have dead-end aisles leading away from the ramp. For such aisles the parking stalls must be placed at 90° angles to the aisle in order to allow entrance and exit in opposite directions.

When circular ramp systems are located near the center of the garage, it is often necessary to allow only one-way travel in the aisles, so that cars may leave and enter the ramp system properly. Either angle or 90° parking can be used in such instances.

Angle-parking is generally preferred by customers, since it more nearly resembles their street-parking habits. As shown above, angle-parking requires deeper stalls and narrower aisles than 90° parking and fewer cars may be parked per 100 feet of aisle. In addition, there is the unused triangular area at each end of a row, and additional cross-aisle space for one-way travel that must be considered as added to the gross area per car parked. In

parking lots the stalls of adjacent sections may be inter-meshed as shown in Figure 32, with a resultant saving of space; however, this is not often practicable in garages due to the interference of columns and walls.

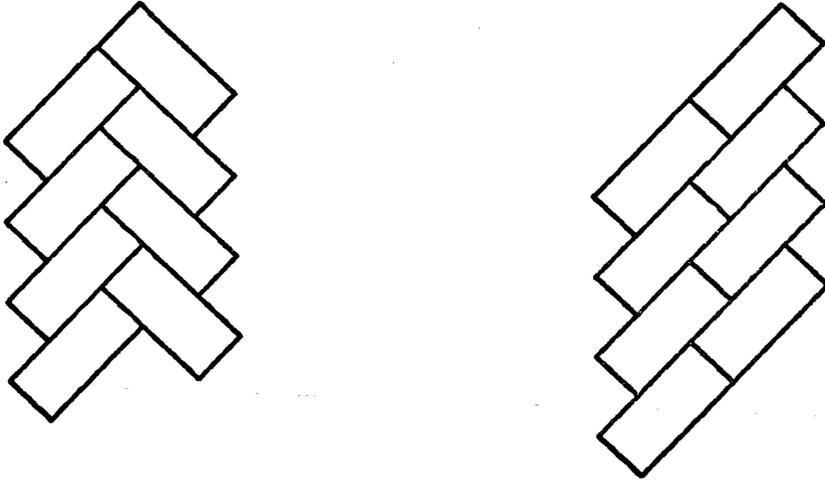


FIGURE 32. Intermeshing of Angle Parking Stalls

Perhaps the most important reason for using angle-parking is the need to use parcel dimensions that do not allow an integral number of 90° Unit Parking Depths.

Aisle Layouts and Minimum Turns

Parking floors must make the greatest use of the area available, with special attention to shape and dimensions. The Unit Parking Depth should be fitted into the dimensions of the land parcel, with aisles placed accordingly, to allow the maximum number of stalls. Certain other considerations that affect the aisle layout will be discussed in the following paragraphs.

The aisle system should minimize the number of turns. All turns on parking floors must be made on a flat surface; superelevation is not practicable. The layout in one garage is shown in Figure 33. Three right-angle turns are required to reach any stall in

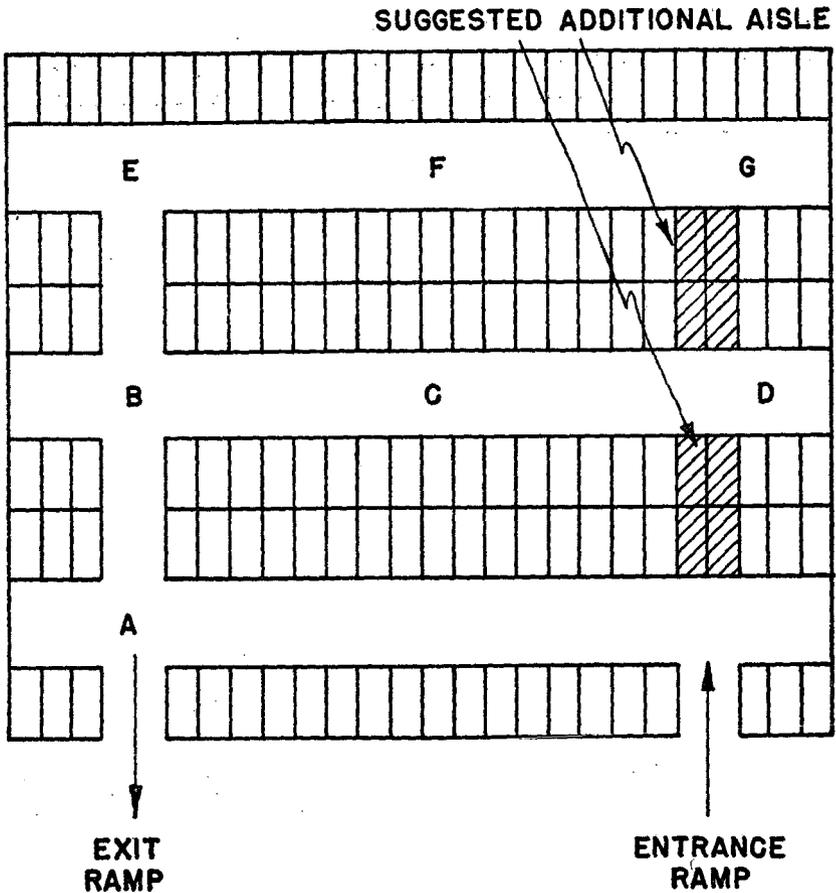


FIGURE 33. Aisle Layout Requiring Excessive Number of Turns

aisles BD and EG. In the garage illustrated, travel times along the aisles were taken, measured from the time that each car left the entrance ramp to the end of forward motion preceding the backing into a stall, with the results shown in Table VIII.

The major part of the travel-time is taken up at turns. The difference in travel-time between points E and F, which includes a right-angle turn, is five seconds, while between F and G—the same distance but without a turn—the time is two seconds. The most difficult turn is at A. This turn is further complicated by the exit ramp, yet 70 percent of the cars must include it in their travel

Table VIII

TRAVEL TIMES AND DISTANCES TO POINTS IN GARAGE LAYOUT
SHOWN IN FIGURE 18

<i>Travel From End of Entrance Ramp to Point</i>	<i>Travel Distance in Feet</i>	<i>Average Travel Time in Seconds</i>
A	120	8
B	170	16
C	246	20
D	322	23
E	216	18
F	292	23
G	368	25

path. A much-improved aisle system would result if another aisle were cut through opposite the entrance ramp, as shown by the cross-hatched area. In this case, only one turn would be required to reach any stall, the travel-time might be reduced by one-half, and the accident-hazard would be materially decreased. Eight stalls would be eliminated, but the benefits would seem to warrant it, and these stalls could be used for temporary storage when others were full.

Dispersion of Activity

In the same garage, excessive delays were caused by cars parked or un-parked near points A, B, and E. In peak periods as many as five attendants were forced to wait at one time while one car was being moved, and were often further delayed by a second similar operation. The layout of aisles should allow access to many different stalls without blocking. This can be accomplished by additional cross-aisles, by eliminating parking on cross aisles, and by alert operation that disperses attendant movements over all floors and does not allow filling the garage floor by floor and stall by stall.

Minimum Travel

Although travel distances in parking garages are not great in absolute terms, the attendants must be moving all day long, either driving or on foot, and a small reduction in distance for each car

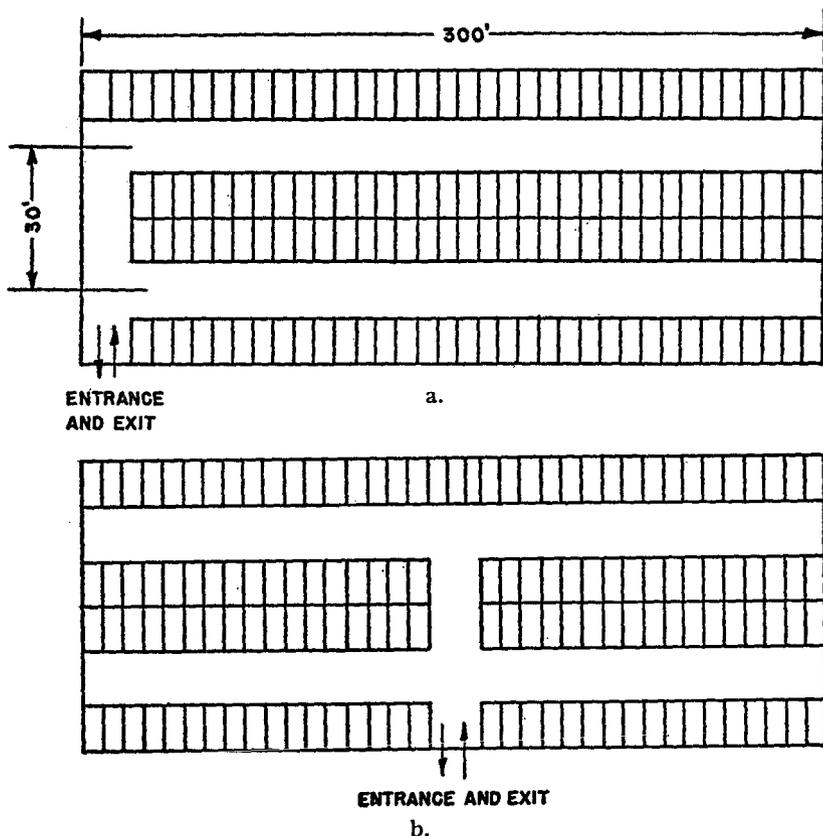


FIGURE 34. Effect of Aisle Layout on Length of Travel Path

parked may result in a large over-all saving. The average floor speed of vehicles measured in this study was 13.0 ft./sec. and of attendants walking 5 ft./sec., which means that each additional foot of travel requires one-quarter of a second of attendant's time. The effect of this small amount of time may be shown in the comparison of two layouts in Figure 34. The travel path for the average car in Figure 34a, assuming an equal use of stalls, would be $150 + 30 = 180'$, while in Figure 34b, it would be $75 + 30 = 105'$. The difference in average travel-distance is seventy-five feet a car; in time it is $0.25 \times 75 = 18.8$ seconds per car.

For a garage handling 700 cars a day this time saving would

amount to more than thirty-five man-hours a day. Although the layout shown in Figure 34b may not be practical for other reasons which govern ramp location, the conclusion is obvious that the travel distances, both for vehicles and drivers, should be kept to a minimum. For vehicles, this may be done by providing direct travel paths on access aisles and by a central location of ramps. *For drivers, who consume more travel time on foot than otherwise, the interfloor driver travel means should be located as near as possible to the centroid of the parking area, with auxiliary means as required.*

The question of one-way or two-way aisles is generally resolved by the selection of the ramp system and in fitting the Unit Parking Depths to the dimensions of the land parcel. There appear to be no distinct advantages in making aisles one-way, unless it is necessary in conjunction with the ramp system.

Most land parcels do not have dimensions which are multiples of Unit Parking Depths; hence a compromise must usually be made in fitting the stall layout to the plot. The most obvious compromise is to park a double row of cars on one or both sides of the aisles, with the added advantage of decreasing the gross area per car. This practice is difficult in garages where customers park their cars, but it may be used where attendants do the parking.

The principal difficulty in double-row parking is the need to move a front-row car in order to un-park a rear-row car. If an attendant must move a front-row car, park it in the aisle, un-park the desired rear-row car, replace the first car, and return to the second, a great deal of time is consumed. This time may be reduced somewhat if an open space is available in which to leave the front-row car, as shown in Table IX.

It appears that about forty-five seconds are required to move a front-row car to a nearby stall, a 50 percent saving over the eighty-nine seconds required to park it temporarily in the aisle and then replace it in the stall after driving out the rear-row car.

To accomplish the time-saving indicated, it is necessary to divide the double-parking rows into sections, in which the maximum number of cars parked is one less than the number of stalls.

Table IX

TIME REQUIRED FOR UNPARKING CARS FROM SINGLE AND DOUBLE ROWS

Action of Attendant	Unparking of Single-Row Car Time in Seconds	Unparking of Double-Row Car if Front-Row Car is Reparked in Another Stall Time in Seconds	Unparking of Double-Row Car When Front Car is Stored Tempo- rarily in Aisle and Reparked in Rear Stall
			Time in Seconds
Get in, Start Front Car		8	8
Drive Out Into Aisle		8	8
Back Into Other Stall		15	
Stop, Get Out		6	6
Walk to Rear Car		7	7
Get in, Start	8	8	8
Drive Out	8	9	9
Stop, Get Out			6
Walk to Front Car			7
Get in, Start			8
Back Into Stall			15
Stop, Get Out			6
Walk to Rear Car			9
Get in, Start			8
Total	16 seconds	61 seconds	105 seconds

By this means, a nearby open stall is assured whenever a front-row car must be moved. *The real time saving inherent in single-row parking should not be overlooked.*

Difficult Stalls

A factor not apparent in most garage layouts, but very real to drivers, is the existence of difficult parking stalls. Examples of such stalls are shown in Figure 35. The exact cause of the difficulty in parking in these stalls is not always clear, but generally stalls parallel and adjacent to walls or ramps should be avoided. Since such stalls exist at the end of every dead-end aisle, they cannot be entirely eliminated, but the aisle layout can keep the

number at a minimum. A few long aisles are better than many short aisles.

Eliminating Columns

To avoid the interference of columns with parking stalls, it is desirable to make the column layout with clear spans equal to the Unit Parking Depth. By this means, the stall-widths can be varied

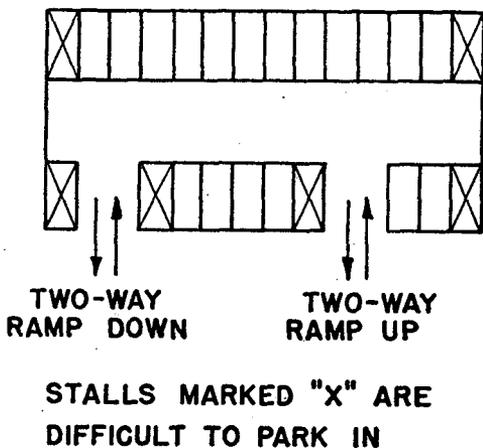


FIGURE 35. Examples of Difficult Parking Stalls

over a period of years to meet the requirements of current vehicles. For today's cars, an 8 foot or 8 foot, six inch parking stall may be adequate, but many operators, speaking from bitter experience, say that since future cars may be wider, more space should be allowed. Conversely, if a trend towards narrow vehicles should occur, as already indicated by the Willys, Crosley, and Studebaker cars, stall-widths can be correspondingly narrowed and additional cars placed in the same area. The problem of providing flexibility in the stall-lengths and aisle-widths is not so easily solved; however, some adjustments in stall-widths can provide easier turning in the aisle. The additional cost for providing the relatively long clear spans of 58 feet may well be justified as insurance against the early obsolescence of a garage. There appear to be no major construction difficulties in providing such spans

in concrete or steel and, in fact, some garages have already been built with 100 foot clear spans.

In the design of some parking garages, such as multifloor underground structures, and those which provide a base for office buildings and other primary uses, it may not be feasible to provide the clear space between columns required for the best layout. This should be accepted as a severe limitation upon the layout of storage floors and the column spacing should be carefully chosen to avoid further obsolescence by reason of the change of the car dimensions. Minimum clear width between column faces for parking three cars abreast should be 27 feet 6 inches and the Unit Parking Depth should be maintained.

CONSTRUCTION DETAILS

Many garage operators have found a curb about column bases useful in reducing fender damage. Other garages have provided quilted padding on column faces at fender height. Simple guards of this type will result in fewer damage claims.

In one garage, repeated damage had been caused by knee braces at the rear of parking stalls as shown in Figure 36. These braces were at just the right height to damage rear fenders and tail lights, since the rear bumper did not limit the motion of the car before these parts struck the brace. Such difficulties should, of course, be avoided in the design and layout.

It is desirable to have some flexible and permanent type of bumper stop at the end of stalls to avoid damage to the walls and columns. A flexible steel or wooden stop is satisfactory; however, it is to be remembered that the thickness of this stop must be subtracted from the effective depth of the parking stall. Wheel stops are not satisfactory because of the greatly varying rear overhang of different model cars.

Wheel guides either between stalls or between wheels are sometimes used to guide cars into stalls. Such guides usually consist of a low concrete island. As with many other controversial items, the attendants in the garages that have such guides say they are useful in parking, while attendants in garages not having such



FIGURE 36. Example of Knee Brace Which Causes Damage to Cars

guides say they would be a nuisance and useless. The author observed that such guides prevented considerable damage in some customer-parking garages observed.

The required ceiling height of storage floors has been reduced in recent years by lowering car heights and by recognition of the fact that a parking garage is a one-purpose building and need not be designed for ready convertibility to other uses. Some garages in the past have been designed with higher ceiling heights to provide for night parking of trucks during periods of minimum passenger car demand. This, however, requires the designing of a truck parking garage rather than a passenger car garage, with greater floor loads and other design factors.* The principal reason for minimum ceiling heights is the reduction in ramp grades and lengths. An objection to low ceilings expressed by some operators and customers is the damage done to and by radio aerials. It is believed, however, that sufficient ceiling height to allow for all radio aerials cannot be justified, and that the problem may be satisfactorily solved by having a floor-man or attendant lower the aerial while the car is in the reservoir space. With these considerations, a clear ceiling height of 7 feet 6 inches to 8 feet is recommended.

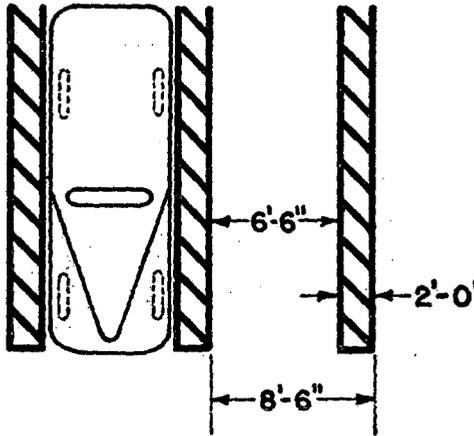
STALL LOCATION SYSTEMS

It is of great importance to the efficient operation of a garage to locate cars quickly for delivery to customers. This involves design and operation; the location system chosen should be consistent with the floor layout. Several systems are described in Chapter IX. The location numbers used should be painted on columns or floor beams adjacent to the appropriate stall. Some garages have columns painted in distinctive colors on each floor, corresponding to that of the identification tickets for that floor.

* The combination of passenger car and truck parking is not often practical from an operational viewpoint. The peak outbound flows of daytime parkers occur during or after the period when trucks are coming in to be parked. The parking of trucks is a slow operation, which will greatly interfere with other movements. More important, labor conditions do not allow the trucks to be held over until after the outgoing passenger car peak has passed.

FLOOR MARKINGS

Parking stalls are usually designated by paint lines four to six inches wide along the floor between stalls. It is helpful in backing into stalls if this line is extended up the wall for a distance of four to five feet as a guide. An effective stall-marking system was observed in one garage: the entire inter-car space was painted to aid in parking the cars in the center of the stalls. The painted area may be painted solid or striped, as shown in Figure 37.



ALL PAINT LINES 4" WIDE

FIGURE 37. Recommended Stall Delineation System

In customer-parking garages, customers were not familiar with the proper lateral spacing in the aisle for ease in backing into stalls. Intending to back into a stall to the right of the aisle, they would often drive too far to the left of the aisle, so that the left front bumper was obstructed by cars parked on the left as the wheels were turned. As a possible solution to this problem it is suggested that guide lines might be painted down each side of the aisle, one for backing into stalls on the left and one for backing into stalls on the right. In operation, the driver would place the left wheels of the car along the proper line and drive slightly past the stall in which he intended to park. If the lines are properly placed, he would avoid interference with cars on the opposite side of the aisle. Such a system is shown in Figure 38.

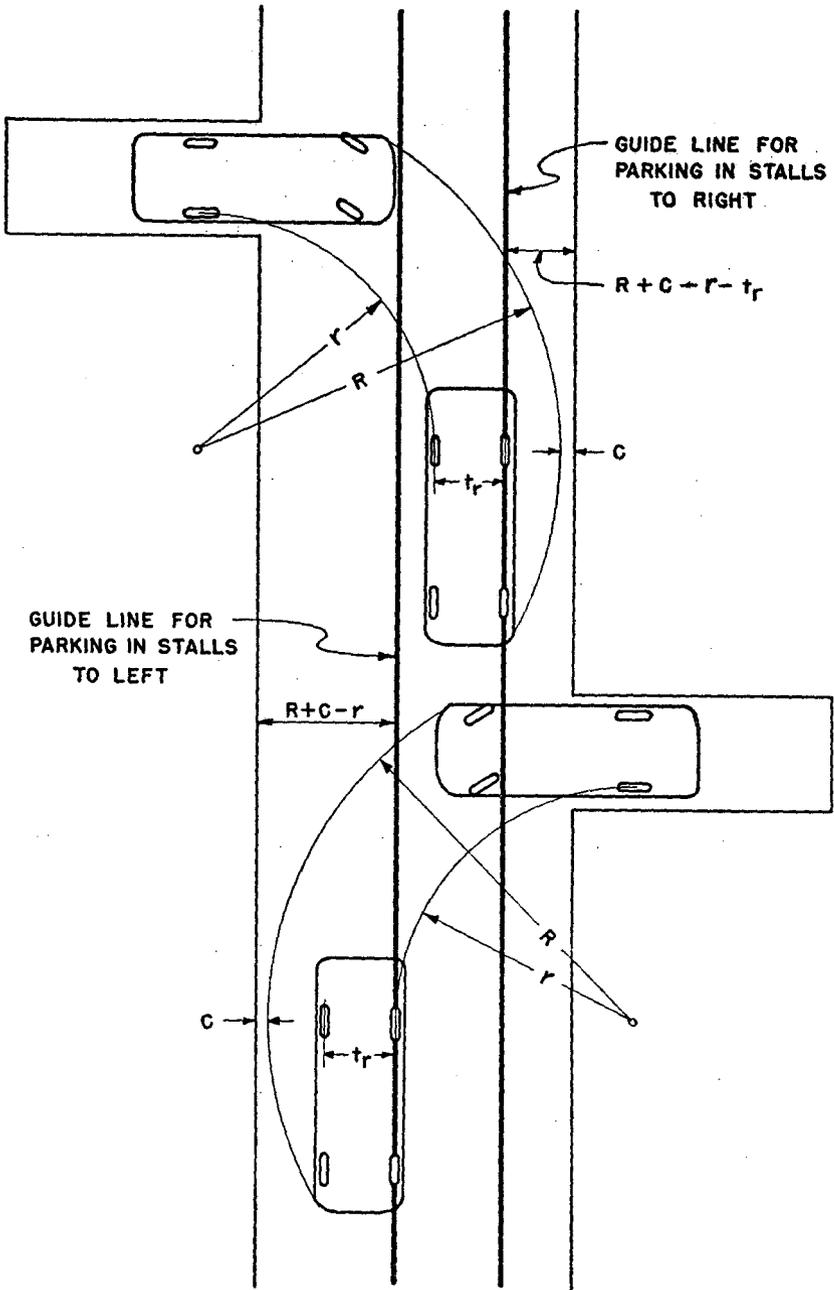


FIGURE 38. Lines in Aisles to Guide Drivers for Backing Into Stalls.

The distance from the right side of the aisle to the guide-line for left-hand stalls is equal to $R + c - r$, and the distance from the left side of the aisle to the guide line for right-hand stalls is $R + c - r - t_r$. Evaluated for a one foot clearance distance and the design vehicle, these formulas indicate that the lines should be spaced 9 feet, 10 inches from the right side of the aisle and 4 feet, 10 inches from the left side of the aisle. These distances are independent of aisle widths; for a twenty-two-foot aisle, the distance between the lines would be 7 feet, 4 inches, center to center. The lines should be about 6 inches wide.

Consideration of this proposal will indicate that the design-vehicle using such a line will clear the cars on the opposite side of the aisle if the wheels are turned the full amount, and, hence, will clear if turned less than the full amount. Cars with a shorter wheel base and smaller turning circle than the design-vehicle will clear more easily. Cars with a longer wheel-base and greater turning circle must be driven slightly inside the guide lines toward the center to clear.

With a little experience, such guide lines might be used to determine the proper distance to drive past a stall for backing in. For this purpose the lines might be dashed at five-to-ten-foot intervals.

Signs

All vehicle paths should be clearly marked by legible well-lighted signs, such as up and down ramps and one-way aisles, for customer-parkers and newly-employed attendants. The usefulness of such signs as SLOW, or DRIVE CAREFULLY is doubtful. In customer-parking garages, information signs should be strategically placed so customers need not wander around to ask directions to cashier's cage, elevators, and rest rooms. In one garage, a single sign on each floor indicated the elevator, but the sign was not visible over more than one-fourth of the floor. Proper signing in customer-parking garages is good public relations. And it reduces the possibility of accidents.

SUMMARY

Though storage floors must be laid out to accommodate as many cars as possible, overcrowding will result in inefficient operation.

The layout of stalls and aisles can be based on current model cars, but the structural features of the building should accommodate cars that may be built twenty or thirty years hence. To this end, it is strongly recommended that columns between parking stalls be eliminated wherever possible, making the clear span between columns equal to the width of an aisle plus a stall on each side (Unit Parking Depth) .

Back-in stalls require less total area per car than do drive-in stalls for 90 degree or 60 degree parking; drive-in stalls require less for 45 degree parking. Parking stalls at 90 degree angles to the access aisles require the least total area per car. Minimum dimensions for layout of a storage floor with 90 degree back-in stalls are:

Stall length	18 feet
Stall width	8 feet for attendant-parking 8 feet 6 inches for customer-parking
Aisle width	22 feet
Unit Parking Depth	58 feet

These values are based on the dimensions of 1947 model cars, the minimum time required for parking and unparking, theoretical formulas for car movements, and measurements of current practice by both parkers and garage operators.

DESIGN OF RAMP SYSTEMS

Cars may be stored on a single level—a parking lot, for instance—with the greatest efficiency since the entire area may be devoted to stalls and aisles. In most downtown districts, however, high parking demand and land costs require storage of a greater number of cars than can be taken care of on one level. Additional storage levels either above or below, require some of the floor area to be diverted for reservoir space, walls, columns, and ramps. Of these, ramps require the largest area, and the most careful planning in location and design.

The simplest form of garage—the parking deck—consists of two storage levels connected by a ramp.¹ A simple ramp system may be used, because the amount of ramp travel is small. The increase in storage space provided by the upper level must be greater than that which is lost to the ramp and columns on the ground level.

To provide additional storage, more levels may be added above ground. The space lost to ramps on the ground floor is not increased until enough storage space is added to require larger reservoir space and a more extensive ramp system. The space required on intermediate decks is increased, because of the through movement of cars to and from the upper floors.

The area of the main floor which is diverted to ramps in an underground garage is the same as for the more usual above-ground building. When both underground and above-ground storage levels are used, two sets of ramps must be provided on the main floor, thus diverting more area.

The choice of ramp types and number of floors must be based on the parking demand and the shape and dimensions of land parcels. Certain minimum physical dimensions of ramps are

¹ In some cases, the topography of the site is such as to allow direct entrance to several levels from different streets or from a single steeply sloping street. This is a desirable arrangement, but is not strictly a ramp garage since the street serves the ramp purpose.

required to provide for turning movements, passing, and clearance. No single type of ramp is best for all garages. The principal types are discussed in the following paragraphs, with the advantages and disadvantages of each. The relationship of ramps to the basic parcel of land on which they are to be applied will be developed later.

Many ingenious and varied ramp systems have been devised, patented, and built, and each applies to some conditions of parking demand and land parcels. Some types, it is claimed, provide a more efficient use of floor area. Close consideration will reveal that, if a standard of stall and aisle dimensions is met, saving in area per car can be gained through ramp arrangements only at the expense of: (1) making ramp grades steeper; (2) using single ramps for up and down movements (i.e., two-way movement on single-lane ramps); or (3) combining ramps and access aisles (i.e., placing parking stalls adjacent to the ramp system). If area per car is the controlling factor, similar savings can be achieved by (4) combining access aisles and parking stalls (i.e., storing cars in the aisles); or (5) using multiple rows of parking stalls, though these devices do not directly affect ramp arrangement. Each of these "savings" can be accomplished only at the sacrifice of some operating efficiency.

Time is as important to ramp travel as it is elsewhere in operation of a garage, and must be considered in any comparison of ramp types. The actual travel-time on ramps is not large, and varies little among different ramp systems. The principal time-difference is the delay caused by conflicting movements that limit capacity of ramp flow. Other aspects of ramps that must be considered are accident hazard, cost of construction, and ability to accommodate the vehicle and its driver.

Ramp vs. Elevators

Freight elevators may be used for the movement of cars between the main and storage floors. The significant difference between ramps and elevators is the rate of handling vehicles, or headway. Ramps provide continuous capacity, and cars can be operated on them almost bumper-to-bumper; an average headway of ten

seconds is comfortable to attain. Elevators can only operate intermittently, and at best cannot be expected to handle cars faster than one a minute. Peak hourly flows of 320 cars an hour (see p. 37) would require six elevators, while not taxing the capacity of a ramp system. Although many older garages are equipped with elevators, this type is now obsolescent because it is less efficient and has a higher operating cost. The general discussion throughout this report will be concerned with ramps. A section at the end of this chapter briefly describes the operating characteristics of the elevators now in use.

ANALYSIS OF MOVEMENTS

The term *ramp* as used in this discussion refers to the *sloping surface* that connects two floors. *A ramp system includes the ramps connecting all floors, plus any portions of the storage floors included in the paths of cars moving up and down.* In multiple-floor garages, the individual ramps are placed one above the other to conserve floor space and simplify construction. *Whatever type of ramp system is employed, cars traveling through a number of floors must follow an approximately circular or elliptical path.*

One-way vs. Two-way Ramps

If a single ramp connects a pair of parking floors, it must be used for both up and down movements; that is, as a two-way ramp. If *separate travel paths* for up and down movements are provided, even though immediately adjacent and integral parts of the same ramp structure, they are termed one-way ramps in this discussion.

Two-way ramp systems nominally use less space, but wide sections must be provided to allow cars traveling in opposite directions to meet and pass. Even though the sloping sections are built wide enough for two cars to pass, drivers generally will not do so. Instead, they will cut the corners closely, making a curved path on the ramp, and pass other cars only on the level sections. For this reason, in one garage, cars were actually stored on an otherwise unused lane of ramps. Numerous delays are caused by two-way

ramp travel, as well as accident hazards, which are characterized by squealing tires and sudden stops. Examples of two-way ramps are shown in Figures 39 and 43.

One-way ramps are necessary in all large garages to provide capacity for peak movements and to avoid delays and accidents. Two-way ramps are satisfactory for small garages. The one-way ramp is so much more common, that in subsequent discussions this type will be assumed unless otherwise stated. Several examples of one-way ramps are shown on later pages, including Figures 41 and 48.

Clearway vs. Adjacent Parking Types

Ramp systems of all geometric shapes may be divided into two types, according to the amount of interference between vehicles moving on the ramp system and those which are parking and un-parking. Ramp systems designed on the "clearway"² principle provide a completely separate path for vehicles traveling up and down, so that there is no conflict with parking and un-parking movements. Ramp systems in which part of the ramp-travel is performed on access aisles may be called the "adjacent parking" type. The number of stalls adjacent to the ramp system may vary from a small number up to the capacity of the garage.

The adjacent parking type requires less area per car parked because of the two-fold use of the travel paths. For the same reason, more delays to vehicle movements occur, and more accident potential exists. The type can be used to advantage on smaller land parcels. Examples of this type of ramp system are shown in Figures 40 and 44.

The clearway type provides for the safest movement of cars with the least delay, and is very much to be preferred for customer-parking garages. As will be seen in later paragraphs, this type of ramp system must be located and oriented in certain ways which may not be feasible in some land parcels. Figures 42 and 46 are typical of clearway ramp systems.

The actual travel speeds for free-moving vehicles on the two

² The "Clearway Ramp" was invented and patented by the late H. L. Woolfenden. In this text the term clearway is used in a general sense.

types do not vary greatly, as can be seen from Table X. The delay to vehicles moving on the adjacent type ramp system caused by parking or unparking vehicles is difficult to measure exactly, but must be recognized as a sizeable quantity. One car stopping in the aisle and backing into a stall will take twenty to thirty seconds, if stall and aisle dimensions are sufficient to provide easy movement; individual blockings as great as one minute were measured in some older-type garages. If a second car is forced to stop for such a movement, additional time is lost to it because of the starting time required by the first. The delays caused by parking and unparking on the lower floors will be greater than for the upper floors, because of the larger number of cars passing up and down the ramp at the lower levels.

Straight vs. Curved Ramps

Individual ramps may be built with either straight or curved alignment, but as pointed out, the travel path on a ramp system must follow a turning movement, repeated for each floor. The geometrical difference between various designs is whether or not the turns are made on the ramps, or on the parking floors between them.

Straight ramps, easiest to construct, fit into the rectangular shape of most land parcels with least waste. Drivers have an unrestricted view on the ramps, but must negotiate a turn at both top and bottom, where the sight-distance is restricted both horizontally and vertically. Banked curves may be built into the ends of the ramps but cannot provide for smooth turning without the use of considerable extra area. In most garages with straight ramps, the turning movements are made on the flat surface of the parking floors. Figures 39 through 45 illustrate several ramp systems with straight ramps.

Curved ramps are usually of uniform radius. They may be classified as circular or semi-circular, depending on whether or not the travel-paths turn through 360 degrees or 180 degrees between each pair of floors. They are inherently of the clearway type. The three principal kinds, discussed later in detail, are illustrated in Figures 46 through 48.

The floor area devoted to the ramps themselves is greater for curved than for straight ramps. Considered as a system, however, there is proportionally less advantage to the straight ramp type because wide turning paths must be allowed on the floors. In either case, parking area is lost adjacent to the curved portion of the travel path because rectangular stalls cannot be fitted to the curves. Considering stability of cars and comfort of drivers, the basic requirement of turning movements can be better satisfied by curved ramps, because turns can be banked to balance centrifugal force.

Concentric vs. Tandem; Parallel vs. Opposed

One-way ramp systems may be classed as concentric or tandem, depending on whether the travel-paths of vehicles moving up and down between two floors revolve about the same center or separate centers. Circular ramps are usually built to be concentric, to save space and to provide a flatter grade for upward-moving cars. Straight ramp-systems may be built either concentric or tandem, as will be shown by specific examples in later paragraphs. Figure 44 shows a tandem system. Other types illustrated are concentric systems.

The turning movement of vehicles traveling a ramp system may be either clockwise or counterclockwise. Some designers believe that all ramp-turns should be counterclockwise, since the driver is then seated on the inside of the turn and can perhaps control his car better.

For cars to rotate in the same direction on a circular ramp system, the up-and-down ramps must be sloped in opposite directions; that is, the ramp surfaces are *opposed*. If the up and down ramps are part of the same, or *parallel*, surfaces the cars must rotate in opposite directions. Both types are illustrated in Figures 47 and 48. There appeared to be no great difference in ease or speed of operation. The parallel type is easier and cheaper to construct.

The terms parallel and opposed may be applied to concentric straight ramp systems in the same way. If the up-and-down ramps are parallel surfaces between any floor, the cars must rotate in

opposite directions; if the surfaces are opposed, the cars rotate in the same direction.

For straight-ramp systems in tandem, the terms parallel and opposed do not have a specific meaning.

GEOMETRIC TYPES

The different combinations of ramp features are almost as numerous as are parking garages. The following paragraphs describe the more common and significant types now in use. Floor-to-floor travel distances, times, and speeds for typical garages are summarized in Table X.

The simplest, and probably the earliest, type of ramp is the Two-way Straight Ramp. As shown in Figure 39, cars traveling between successive floors travel along elliptical paths, most of which are on flat surfaces, and all up-and-down travel takes place

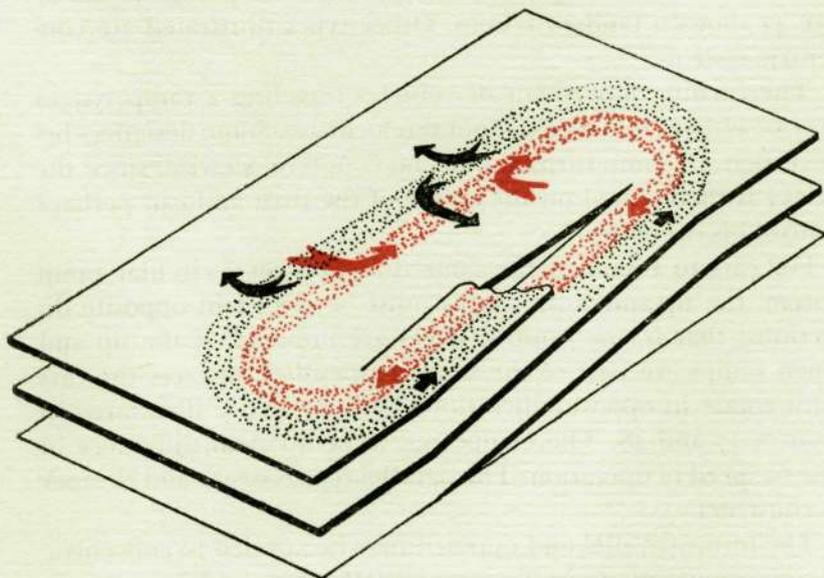


FIGURE 39. Two-way Straight Ramp System

on a series of sloping parallel planes, one above the other. The advantages of such a ramp system are that it may be placed in a relatively narrow building, that it takes up a small area, and is simple to construct. Disadvantages are that sharp turns must be made in getting on and off the ramp and that the congestion of two-way travel is hazardous and delaying. This type of ramp is most often used in parking "decks", that have one level of parking above the street and hence no through-movement from upper floors. The time for unobstructed movements on a typical ramp of this type was about seven seconds per floor for up-travel and five seconds per floor for down-movement.^a

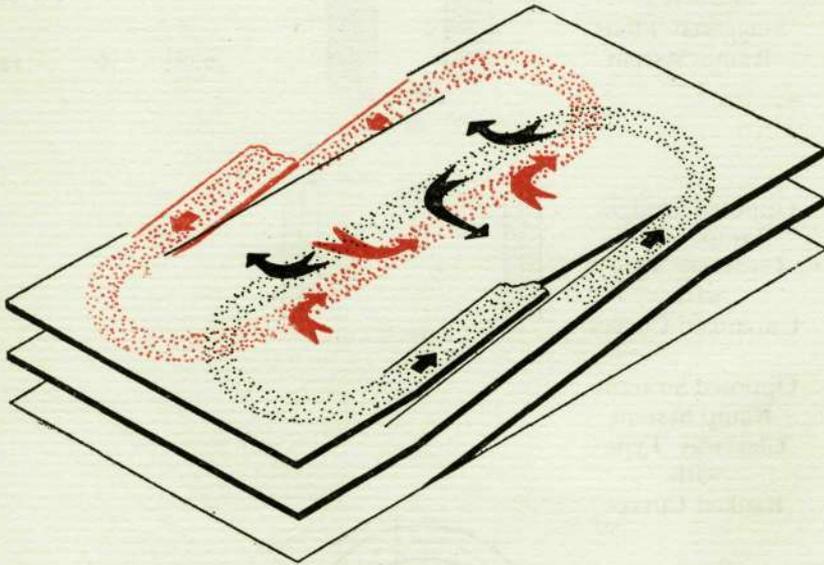
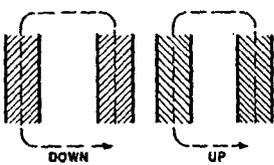
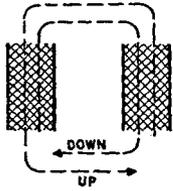
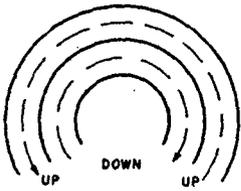
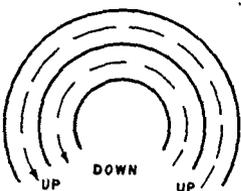


FIGURE 40. Parallel Straight Ramp System

^a Measured in an attendant-parking deck on a ramp sixty-five feet long with a bad 180° flat turn at the top of the ramp and a partially banked 90° turn at the bottom. The up movements ranged from five to nine seconds, the down movements from four to seven seconds. The greater time required for the up travel may be accounted for by the approach to the blind turn at the top of the ramp; for down travel, this turn has been negotiated before the car reaches the ramp. Such physical differences in ramps will greatly affect operating time on the ramp.

AVERAGE SPEED AND TRAVEL TIME FOR FLOOR -

TYPE OF RAMP	SCHEMATIC LAYOUT	UP		ATTENDANT D
		Distance Feet	Average Time Sec.	
One-Way Tandem Staggered Floor Ramp System		178	11.2	10.8
Two-Way Staggered Floor Ramp System		228	12	12.6
Opposed Straight Ramp System Clearway Type with Unbanked Curves				
Opposed Straight Ramp System Clearway Type with Banked Curves				
Parallel Circular Ramp System		230	11.4	13.6
Opposed Circular Ramp System				

* Time values shown for unobstructed movement on ramps.

X

FLOOR MOVEMENTS ON CERTAIN TYPES OF RAMPS*

ING	DOWN		Distance Feet	UP		CUSTOMER DRIVING		
	Average Time Sec.	Average Speed MPH		Average Time Sec.	Average Speed MPH	Distance Feet	Average Time Sec.	Average Speed MPH
3	10.8	11.2	220	18.4	8.1	220	22.2	6.7
	12	12.6						
			230	18.6	8.4	230	24.4	6.4
			134	7.8	11.7	134	9.6	8.4
	8.5	12.0						
			150	23	4.5	95	16.0	4.0

Parallel Straight Ramp

The first step in overcoming the disadvantages of a two-way ramp is to separate the up and down lanes by a central dividing island. The advantages of the rectangular shape and the small ramp-area are retained; but the paths of vehicles moving up and down are the same for the level portion, so that hazards and delays are only partly reduced. To further separate these movements, the up-and-down lanes may be placed on two ramps some distance apart, as shown in Figure 40. The turning movements for the two ramps are performed in different areas, while the straight travel is performed in a two-way movement along the same aisle for both up-and-down movements.

This type of ramp is adapted to buildings with exit and entrance on the same street. The travel-time measured for unobstructed up-movements on a ramp of the latter type was fifteen seconds per floor, of which five seconds was on the ramp.⁴

Opposed Straight Ramp

If one-way straight ramps are pitched in opposite directions, they occupy practically the same area as do parallel ramps, but a basic change is made in the traffic pattern. If the ramps are placed side by side, as shown in Figure 41, the travel paths for through up-and-down movements will fall in the same aisle. (It is possible to separate these travel paths, by having each turn to the outside of the ramp, but this complicates parking movements on the floor.) The conflicting movements are somewhat reduced, as cars moving up and down pass along the common aisle in the same direction of movement. The times and length of travel paths are the same as for similar parallel ramps. Dimensions of the ramp system in a recently completed garage of this type follow:

Length of ramp, measured along slope	93'
Floor-to-floor height	11'
Ramp Slope	13%
Length of travel on floor	245'
Total travel distance per floor	338'

⁴Measured in an attendant-parking garage on a ramp 100 feet long with a partially banked 90° turn at the bottom and 180° turn at the top. The range of travel times per floor was 13 to 19 seconds, and for the ramp 4.5 to 6 seconds. The down ramp in this garage was of a different type.

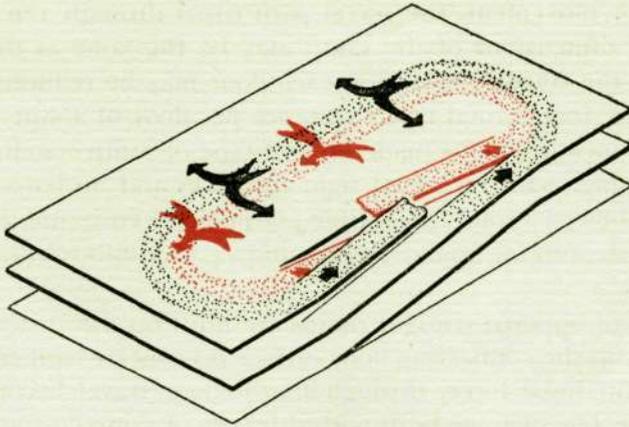


FIGURE 41. Opposed Straight Ramp System, Adjacent Parking Type

Opposed ramps may be placed with the up-and-down lanes some distance apart. This will separate up-and-down movements, shorten travel paths, and provide for clearway operation if desired. This ramp system is illustrated in Figure 42. For each

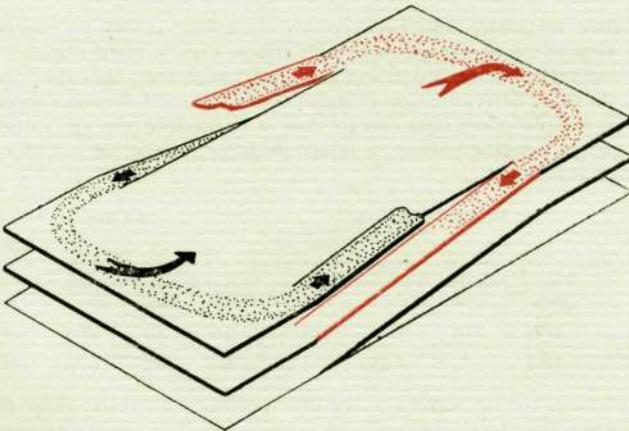


FIGURE 42. Opposed Straight Ramp System, Clearway Type

floor-to-floor movement, the travel path turns through 180 degrees. The dimensions of the ramp may be the same as those above, but the travel distance on each floor may be reduced to about ninety feet, a total travel distance per floor of about 180 feet. Time measurements made on this type of ramp system in an older garage with restricted sight distances and no bank on the turns, showed a total travel time per floor for customer-driving of 18.6 seconds for up-movements and 24.4 seconds for down-movements.⁵

If a pair of opposed straight ramps are built on the clearway principle, and the connecting floor surface is properly banked to balance centrifugal force, through-floor-to-floor travel becomes much easier. On a garage built with this type of ramp customer-drivers showed average floor-to-floor travel times of 7.8 seconds ascending and 9.6 seconds descending.⁶ The advantage of providing banked curves for the turns on each floor is apparent. A slightly larger area is allotted to the ramp system for clearway operation, since no cars can be parked on the travel paths between ramps. Some minor conflicts exist between through-movements and cars entering and leaving the ramp at each floor.

The ends of opposed ramps on the main floor are pointed in opposite directions, so that this type is best suited to garages with entrance and exit on separate streets. It can be adapted for en-

⁵ The travel-time on ramps and between corresponding points on successive floors is closely dependent on the physical restrictions, such as sight distance and width of ramp and on the driver's skill and familiarity with the particular garage. For this reason, an exact determination of travel times was not believed warranted and only enough samples were obtained to show a reasonable average value. In the particular garage described above, a relatively large number of samples was taken with results as follows:

	FLOOR-TO-FLOOR				RAMPS			
	Average (Sec.)	No. of Observations	Standard Deviation (Sec.)	Standard Error of the Mean (Sec.)	Average (Sec.)	No. of Observations	Standard Deviation (Sec.)	Standard Error of the Mean (Sec.)
Up Movement	18.5	105	3.20	0.312	9.0	80	1.60	0.179
Down Movement	16.7	27	2.45	0.47	8.4	67	1.85	0.226

⁶ The range of times for up travel was six to ten seconds for thirty-three cases, for down travel was eight to eleven seconds for twenty cases. The travel distance per floor is 134 feet, of which 88 feet is on the ramp.

trance and exit on the same street, but this requires a 180-degree turn on the main floor, which uses additional space.

Staggered Floor Systems

One of the most ingenious ramp systems is that employing staggered floor levels, invented and patented by Fernand E. d'Humy. The garage building is constructed in two sections abutting a common wall, the floor levels in each section staggered vertically by one-half story from those in the other. Short straight-ramps connect the half-stories, sloped in alternate directions, and separated by the distance required to easily make a 180-degree turn between ramps. One section is usually smaller than the other, containing only one aisle and adjacent stalls, and is called a mezzanine. Any of the combinations of straight ramps described in the above paragraphs may be applied to the staggered floor system. Two examples are shown in Figures 43 and 44.

The travel time per half-floor for *unobstructed* movement was found to be about 6 seconds in all garages with staggered floors for any type and arrangement of ramps.⁷ Because of the adjacent parking feature, however, the through travel is frequently obstructed. In one garage with a two-way staggered floor ramp, a detailed time study was made of each operation, and of the over-all time required by each attendant for a round trip of unparking a car. Measurements of over-all time required were made in 295 cases, with account being made of the stall location and method of interfloor driver travel. Allowing average values for each component operation, the over-all time exceeded the sum of the components by about 15 to 30 seconds, depending upon the stall location. A large part of this time apparently is accounted for by delays on the ramp system.⁸

⁷ In one garage with a tandem staggered ramp, for example, the range of values was 5 to 7 seconds for both up and down travel, with averages of very nearly 6 seconds, in over fifty cases.

⁸ The theory of probability cannot be applied to this type of delay because cars are not spaced on the ramps at random. Drivers tend to travel in groups, because of delays on the ramps, the grouping effect of passenger elevators, and conditions on the main floor.



FIGURE 43. Two-way Staggered Floor Ramp System

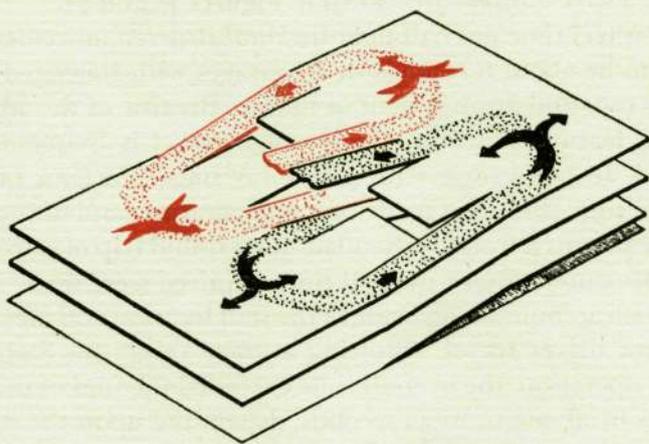


FIGURE 44. One-way Tandem Staggered Floor Ramp System

The staggered floor system of ramps is applicable to small, high-cost land parcels where a maximum use of space must be made. The construction is relatively simple and it fits well into rectangular land parcels. While this system is efficient in terms of floor space per car stall, like all ramp systems employing *adjacent* parking, considerable conflicts arise between cars moving up and

down the ramps and those parking and unparking. The repeated turning movements are made in the aisles, with a continuous series of conflicts possible, so that drivers must be alert and prepared for sudden stops. The amount of bank on the turns can never be sufficient to balance centrifugal force because the portion of the ramp which is parking aisle must be level, or nearly so. These complications make the staggered floor system somewhat unsatisfactory for customer parking, although one garage was observed where it was employed successfully. Moreover, the area required for the two half-story ramps is equivalent to one full-story ramp. Again, to gain a full story of storage space, the same travel distance and vertical movement is required. More existing garages have ramps of this type than any other.

One variation in the staggered floor system utilizes three separate levels, with the two end sections at the same elevation and staggered one-half floor with respect to the center section. An example of this type is shown in Figure 45. The advantage gained is that 50% less turns are required, so that travel time is somewhat reduced. However, the end sections have access to either an up or a down ramp only, so that each car in these sections must be

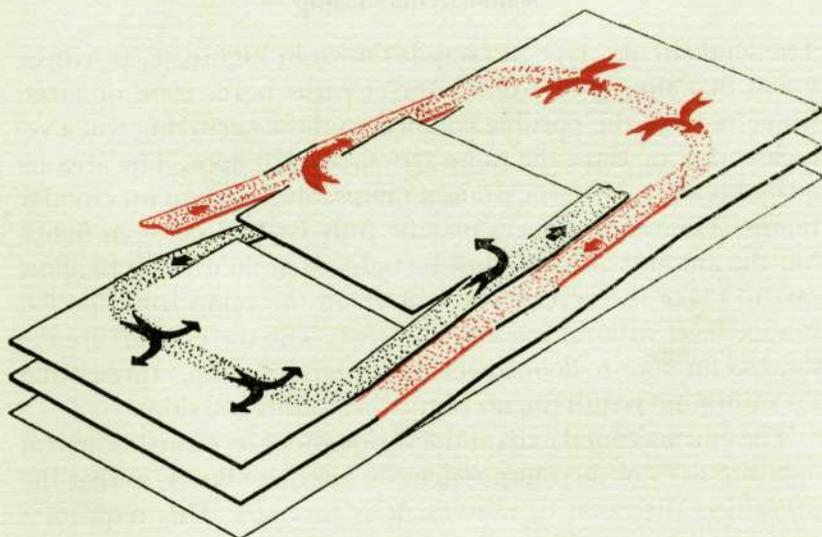


FIGURE 45. Three-level Staggered Floor Ramp System

driven one extra half-floor, either on entering or leaving the parking stall. This feature caused a great deal of confusion in one garage observed, where even some experienced drivers were said to have had serious accidents because of traveling on the wrong ramps.

Sloping Floor

In the sloping floor type of garage, the travel path passes along a series of planes which provide a continuous slope from floor to floor. Cars are parked on each side of the travel path, so that there is no area set aside for ramps in the ordinary sense. Such a garage may utilize a low grade (4% in one case), and hence higher speeds, although the travel distance is greater. Movement is generally two-way, a fact which adds to the congestion of the adjacent parking feature. Cars are parked transversely to the slope, to minimize the possibility of rolling down out of control. The sloping floor principle may be applied to the mezzanine portion of staggered floor garages. No garage was observed in this study with a complete sloping floor design.

Semi-Circular Ramp

The semi-circular type of ramp is shown in Figure 46. It will be noted that the up and down travel paths never cross or meet, which reduces the possible conflicts to those occurring when vehicles enter or leave the ramp system at each floor. The area required is larger than for straight ramps, but less than for circular ramps. The ramp surfaces may be fully banked between floors, but the amount of bank must be reduced at floor levels to allow cars to make the reverse turn off or on the ramp from the flat storage level without too sharp a break. The travel paths are the shortest for floor-to-floor travel for any type of ramp, representing the minimum requirements of turning radius and slope.

The entrances and exits at the various floor levels are located at opposite sides of the ramp system on alternate floors, so that the prevailing direction of movement is reversed. This requires a semi-circular ramp to be placed inside the storage floor area for easy access on all floors.

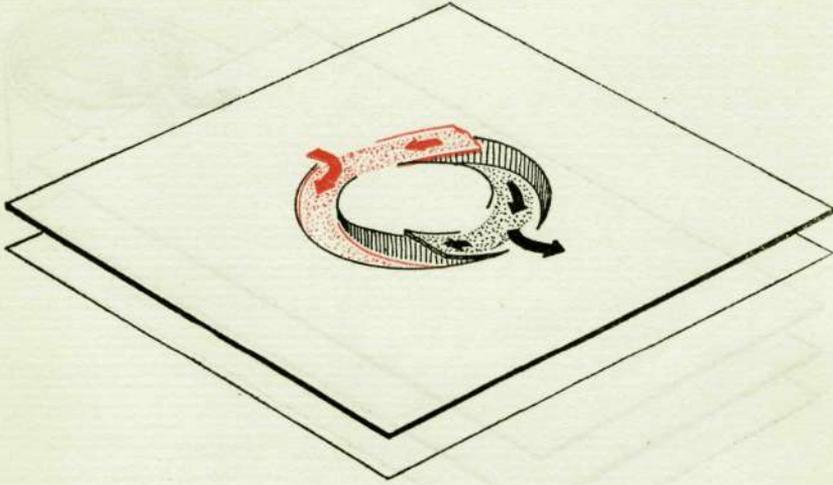


FIGURE 46. Semi-circular Ramp System

Similarities will be noted between this type of ramp and the Opposed Straight Ramp with the up and down ramps separated. Both types have been termed "elliptical" by some authors. The only difference is that the semi-circular ramp combines the climbing and turning movements of the cars, a fact which may be desirable, in order to take the greatest advantage of warped surfaces. In addition, cars entering or leaving the ramp system may do so on a level surface, without any bank.

Parallel Circular Ramp

A Parallel Circular Ramp has a single surface on which the up and down movements are separated by a low medial island as shown in Figure 47. The outer lane is used for up movements since it has a larger radius of curvature and lower grade. The up movement is usually counterclockwise and the down movement clockwise, so that cars approach each other in the normal keep-to-the-right manner.

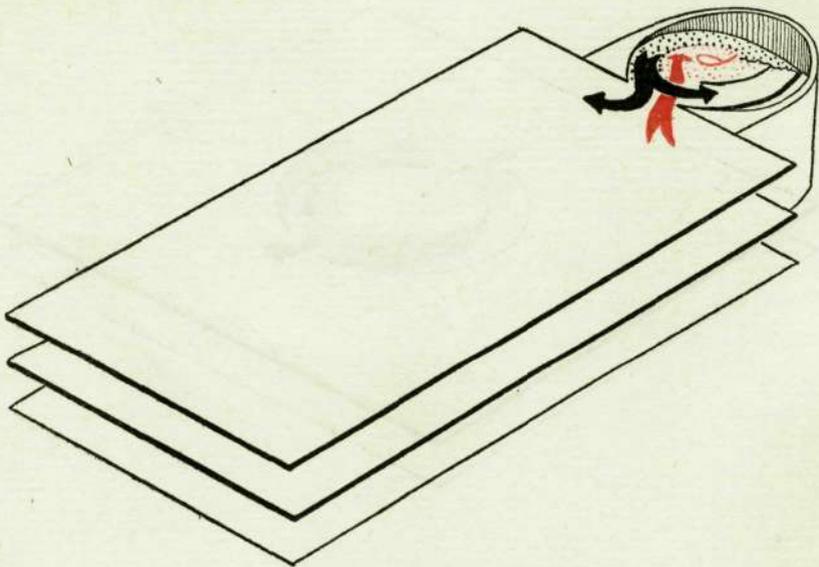


FIGURE 47. Parallel Circular Ramp System

The entrance and exit of circular ramps are located at corresponding points directly above each other on each succeeding floor and cars approach each floor from the same direction. For this reason, they are well-fitted for locations at one end or side of a land parcel. Circular ramps are inherently of the clearway type.

The diameter of a circular ramp is determined by the minimum turning radius of the design vehicle, which governs the radius of the inside lane. The area of such ramps is rather large and the center area is generally wasted, since it is not large enough for the storage of vehicles.

Circular ramps can utilize full banking, and the flatter grade of the outside lane offers some advantage over the semi-circular type. The only conflicts occur at floor levels, and are minimized by the fact that approaching drivers have a relatively clear view of the storage floor.

Measurements made in an attendant-parking garage showed an up ramp 230 feet long with an average travel time of 11.4 seconds,

and a down ramp 150 feet long with an average travel time of 8.5 seconds.⁹

Opposed Circular Ramp

The Opposed Circular Ramp differs from the Parallel Circular Ramp only in the slope and direction of travel of the inside lane. The two lanes are placed at opposite slopes which makes construction more difficult. All car movements are counterclockwise. Some conflict is caused at the floor levels because drivers on the up and down lanes cannot see each other until they reach the floor. This type of ramp is shown in Figure 48.

Measurements in a customer-parking garage showed average travel times of 23 seconds for up movement and 16 seconds for down movement.²⁰

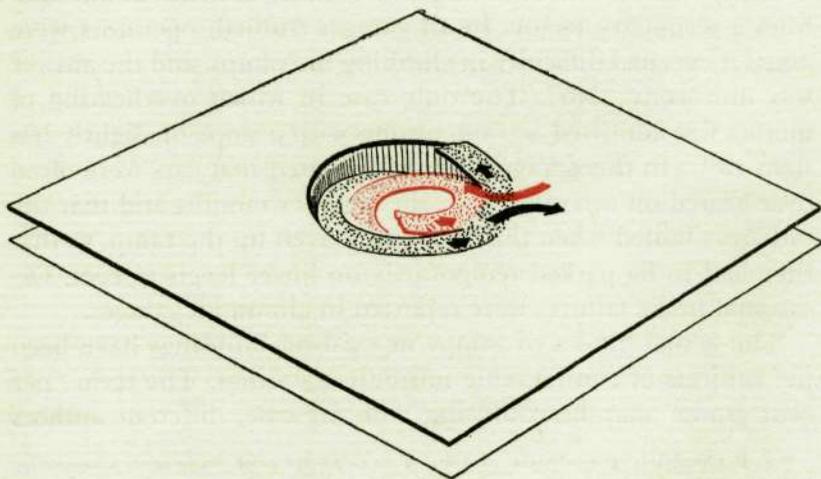


FIGURE 48. Opposed Circular Ramp System

⁹ Measured for 30 cases of up travel, with a range of 11 to 13 seconds, and for 35 cases of down travel, with a range of 7 to 10.5 seconds.

²⁰ Measured on a ramp with an inside radius of 18 feet and travel paths of 150 feet and 95 feet for up and down movements, respectively. The range of travel times for up movements was 18 to 31 seconds for 35 cases, and for down movements 11 to 20 seconds for 44 cases.

RAMP STANDARDS

Throughout the preceding discussion, the various types of ramps have been considered with regard to configuration, travel paths, and travel speeds. Certain standards, such as maximum slope and minimum radius of turns, apply to all types of ramps. The best available criteria for determining such standards are the operations in existing garages. A complete range of variables is not thus available, but data can be obtained as to whether existing dimensions are adequate. An extended program of experimental construction is desirable to more accurately establish such standards, but facilities were not available in the present program.

Slope of Ramps

There is a general agreement among authors that the slope of a ramp should not exceed 12 or 15%.¹¹ The maximum practical ramp grade is limited perhaps by the psychological effect on drivers, with the hill-climbing and braking abilities of automobiles a secondary factor. In all garages studied, operators were asked if cars had difficulty in climbing the ramps, and the answer was uniformly "No". The only case in which overheating of motors was admitted was on a ramp with a slope of slightly less than 10%. In this garage, attendants stated that cars were often over-heated on arrival during the summer months and that the radiators boiled when the cars were driven up the ramp, so that they had to be parked temporarily on lower levels to cool. Occasional brake failures were reported in almost all garages.

The actual grades of ramps in existing buildings have been the subjects of considerable misunderstandings. The term "per cent grade" may be confusing¹²; in any case, different authors

¹¹ E. P. Goodrich, *et al*, op. cit., p. 189. "A 12 to 15 per cent grade is recommended. In no case should the grade exceed 20%."

American Automobile Association, op. cit., p. 132, "... ramps should not exceed 15 per cent grade, and 10 or 12 per cent would be preferable".

Pittsburgh Regional Planning Association, op. cit., p. 42. "Maximum Grades For Ramps. Preferred 15%, Absolute 20%."

¹² Per cent grade may be defined as the vertical rise in feet in a horizontal distance of one hundred feet. In a garage, the ramp grade may be computed by multiplying the floor-to-floor height by 100 and dividing by the length of ramp. For the grades involved, the difference between the length measured along the slope or horizontally is negligible.

quote varying grades for the same ramp. In answer to different questionnaires, the ramp grades for one garage were stated as being 20 percent and 50 percent. In the garages observed in the present study, ramp grades were measured along the center of travel paths in conjunction with time-motion studies. *No grades over 16 percent were found.*

The actual grade to be employed depends on the floor-to-floor height and the space available for ramps. Figure 49 shows the

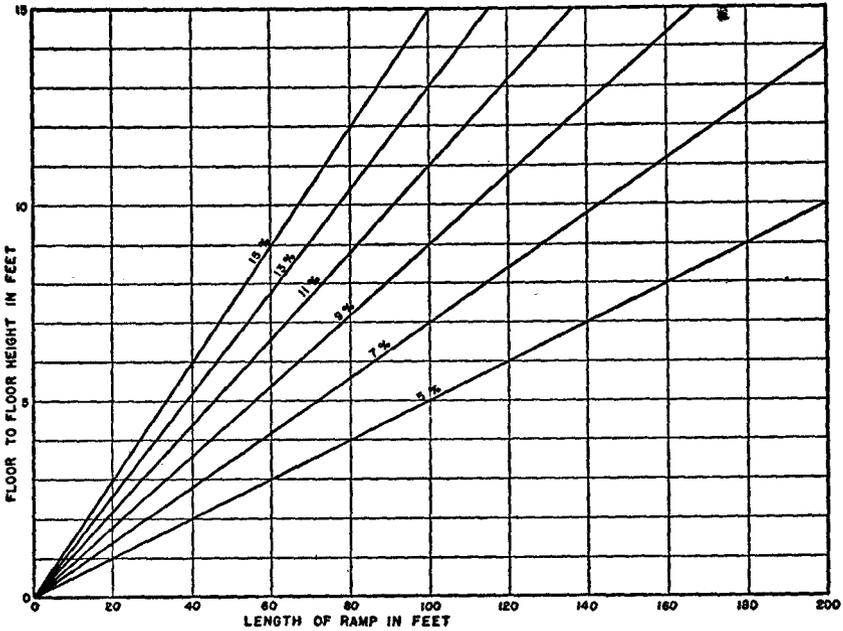


FIGURE 49. Relationship Between Floor-to-Floor Height, Ramp Grade and Length

relationship between ramp-grade, length, and floor-to-floor height. For instance, this graph shows that for a slope of 13 percent and a rise of 9 feet, a ramp 70 feet long is required. Similarly, it will be seen that a floor-to-floor height of 11 feet and a ramp length of 90 feet result in a slope of 12 percent.

Blending of Ramp Grades at Floor Levels

A sharp change in slope at the top or bottom of ramps is unpleas-

ant to travel over, and may cause damage to the lower parts of cars. It is customary to ease these changes by blending the ramp and floor grades in a short vertical curve. The points which determine minimum clearance underneath different vehicles vary as to location, wheel base, height above floor level, and the amount this height is affected by spring action. The critical points are generally the rear bumper (at the bottom of ramps) and some point about midway between the front and rear wheels (at the top of ramps). The minimum clearance is about six inches.

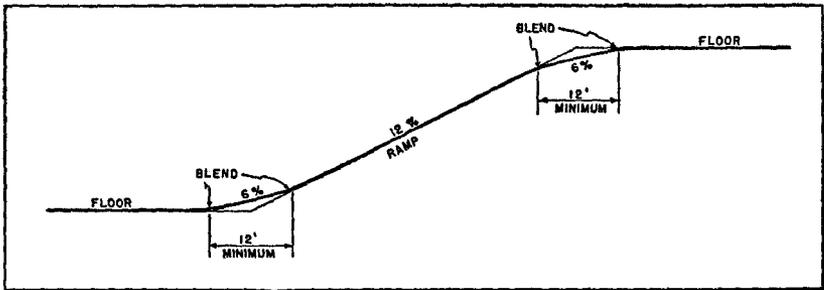


FIGURE 50. Recommended Blending of Ramp and Floor Grades

Several methods of easing grade changes have been used in garages. The refinement of parabolic curves, as used in highway design, is not warranted because of the long curves required, and because precise construction is expensive and hard to attain. A practical method is to break the slope with a straight grade about 12 feet long at a slope equal to half that of the ramp. The ends of this lesser slope may then be blended with approximate curves, thus providing additional clearance and comfort for drivers. This type of construction is shown in Figure 50, in which the vertical scale is exaggerated to show detail.

Some garage owners stated that the blending shown in the drawings was not actually followed in construction, with the result that the ramps had to be rebuilt at these points. The construction difficulties should not be minimized, and it is generally true that a fine accuracy in layout is less important than adequate supervision of construction on this point.

Width of Straight Ramps

The usual cross-section of one-way straight ramps is a lane nine to ten feet wide, with a low curb one foot wide on each side, giving an over-all inside dimension of 11 to 12 feet. Since the tread of standard automobiles is about five feet, and the over-all width less than eight feet, these dimensions provide adequate room for straight-ahead movements. No difficulties were observed in travel on the straight portion of ramps. The end sections, on which cars are completing or starting a turn, must be flared to greater widths, as discussed in the next section on curvature of ramps.

If up-and-down lanes are adjacent, they should be separated by a medial island at least one foot wide. This island, as well as the side curbs, should be not over six inches high, to allow clearance of bumpers and running boards. The curb faces should be sloped back slightly, say one inch from the vertical, and rounded off to avoid damage to tires.

Curvature of Ramps

The repeated turning movements of cars traveling between floors are a primary factor in the design of ramp systems. The radius of this circular path must be kept to a minimum to conserve space and to make the travel distance as short as practicable. On the other hand, very sharp and unrelieved turning will produce a dizzying effect on the driver. To reduce this effect, ramp systems are sometimes laid out with the sharpest curves separated by short straight, or less sharply curved, sections, thus resulting in a somewhat elliptical travel path.

In many garages, the turns required are too sharp for easy driving, as indicated by damage to walls and columns near the ends of ramps. Needless to say, damage is also caused to the bumpers and fenders of cars at these points.

In the garages studied, the smallest inside radius of curb on a circular ramp system was 18 feet. This radius was found in two garages, one with a lane width of 11 feet 8 inches, and the other 11 feet 6 inches. Both seemed to operate satisfactorily. The former, with attendant-parking, had average operating speeds of

12 miles per hour, and the latter, with customer-parking, 4 miles per hour.

The structural limitation on the movements of cars traveling on a curved path is determined by the radius of the outermost point (usually the front bumper) when the car is turning on a minimum radius. The radius of the inside curb must be less than the minimum radius of the inside rear wheel, but not much smaller, or drivers will try to enter the ramp at too sharp an angle and thus get the car crossways of the lane. The relationship between these radii depends on the attitude of the car, which is determined by the extreme corner dimensions, the maximum steering angle, the wheelbase, and speed. Clearance must be provided for the car with the largest outside radius, and all other cars can then travel in the lane provided.

Reference to Figures 23 and 24 reveals that the extreme 1947 model (Packard 2126) has a radius of 30 feet for the maximum outside point. The inside rear wheel will track in a circle of 20 foot radius. This car, and all other 1947 models, are able to travel the ramps described above. Liberal design to allow for future model cars will use radii greater than this minimum.

In a circular ramp system, with the up-ramp placed concentrically on the outside of the down-ramp, the radius of the up-ramp is not as restricted. Because cars are turning at a flatter angle, they will assume a different attitude, and effectively, a narrower travel path. In the garages described above, the outer lanes were 10 feet 6 inches and 9 feet 6 inches respectively. Again, they were satisfactory in operation. To allow overhang of cars on both up and down ramps in a parallel system, the medial island which separates the lanes should be at least 18 inches wide.

It may thus be concluded that the desirable minimum dimensions for a curved ramp are:

Radius of inside lane, face of outer curb	30 feet
Width of inside lane, between curbs	12 feet
Width of outside lane, between curbs	10 feet 6 inches
Width of curbs	1 foot
Width of medial island	1 foot 6 inches

The minimum curvature of semi-circular ramps may be the same as that of circular ramps. It is desirable, however, to make

it somewhat greater, to allow a flatter slope for upward travel. If this is done, the area between the ramps is large enough to store several cars. The diameter may be made equal to the Unit Parking Depth, plus an allowance for columns, in which case the radius of the inside curb would be about 31 feet.

The relationship of slope to radius and floor-to-floor height may be observed from Figure 49. It may be assumed that the effective length of the ramp can be measured along the centerline of the lane. As an example, the vehicle paths for circular ramps of the recommended minimum radius will have radii of 24 feet for the inside lane and 36 feet 9 inches for the outside lane, and lengths of 151 feet and 231 feet respectively. Referring to Figure 49, it may be seen that these dimensions correspond to slopes of 7.5% and 5% respectively, for 11 foot floor heights.

Generally speaking, wider turns should be provided on the approach to straight ramps than on continuously curved ramps, because drivers do not approach them uniformly. In some cases, the ends are flared with an inside radius of as little as 10 or 15 feet. This has the effect of widening the travel paths; it does not reduce the space needed on the outside of the turn.

Superelevation of Ramp Turns

When vehicles travel on curved paths they are acted upon by a centrifugal force proportional to the square of the velocity and inversely proportional to the radius. This centrifugal force must be balanced by other forces, which are developed by the side friction of the tires on the pavement and the superelevation, or bank, of the roadway. In garages, the speeds are low, but the radii are much smaller than on streets or highways, thus resulting in rather large centrifugal forces.

The equation relating these forces is:

$$e + f = \frac{0.067 V^2}{R}$$

where e = superelevation in feet per foot of horizontal width

f = transverse coefficient of friction

V = speed in miles per hour

R = radius of curve in feet

The value of "e" on flat surfaces is zero, which means that all the centrifugal force must be taken up by the friction of the tires on the pavement. As superelevation is provided, the centrifugal force is partially balanced, which may result in easier turning for the driver, or may cause him to feel free to travel faster, whereupon a larger friction will again be developed. Measurements in attendant-parking garages showed values of "f" as high as 0.53.¹² As might be expected, customers developed much less unbalanced centrifugal force, in some cases not driving fast enough to utilize the full effect of bank.

It is not good practice to bank curves too steeply because very slow drivers will have difficulty in keeping away from the inside curb, and because fast drivers may be encouraged to drive at speeds greater than may be safe for other conditions, such as slope and sight distance. The bank used in most garages is 0.1 foot per foot of width. One garage observed has very steeply banked curved sections on the parking floors, connecting opposed straight ramps. The superelevation is not uniform, but increases over a concave surface, so that cars traveling at higher speeds may take advantage of a greater bank. The greatest amount thus available is about 0.15 foot per foot over the width of the tread.

APPEARANCE OF RAMPS

Driving on ramps is an unaccustomed operation to most motorists. Travel paths in garages combine narrow lanes, steep grades, and sharp turns, and drivers must depend more on appearance and "feel" than on experience. It is possible to use architectural and optical effects which will give the motorist confidence and reduce the adverse psychological effect of driving in very restricted spaces. The most obvious means are to make sight distances as great as possible and to provide abundant illumination. Although such devices are intended primarily for customer-parkers, they will also aid in the operation of attendant-parking garages.

Ramp structures should be as open as practicable, to provide

¹² Computed on the basis of speeds of 15 miles per hour, a travel path of 24 foot radius, and bank of 0.1 foot per foot.

adequate sight distances and reduce the feeling of restricted movement. In locations where icing conditions are common, the ramp should be placed in the interior of the building or otherwise protected from storms. In any case large windows or other openings should be provided to allow plenty of illumination and sight distance.

The author visited one garage which had recently commenced a program of cleaning and painting, both of which had been neglected for many years. The improvement was startling, particularly on the ramps. Dirty concrete surfaces blend together under the relatively low light levels in a garage and make driving unnecessarily difficult. Ramp walls should be painted white or some other light color.

The apparent steepness of ramp grades may be reduced by the optical trick of obscuring horizontal and vertical lines of reference. The ramp walls can be painted with stripes of contrasting color, parallel to the roadway surface, or even at steeper angles. The normal angles between vertical columns and the roadway can be obscured by paint markings, or the adjacent structural features may be built with lines either parallel or perpendicular to the roadway.

The illumination of ramps should be given special attention. Windows and other openings should not be placed so that incoming light will blind the drivers. A condition of this type was observed in one garage, and the operator pointed out the indications of repeated collisions with the ramp wall where drivers had been partially blinded by the direct rays of the sun. Artificial lighting should take the form of diffuse illumination or have reflectors definitely pointed away from the direction of travel.

The normal highway guides are not of much value in garages, e.g., paint lines on the floor at the crest of ramps are not in the driver's line of vision. In one garage, drivers were often observed to strike the curb at the approach end of a straight ramp, onto which they were making a 90 degree left turn. The following methods of marking such limiting points are suggested:

1. Hang flexible materials, such as rope, from the ceiling over curb ends.
2. Paint center lines on the ceiling.

3. Place signs over the ramp, such as "TURN LEFT AT TOP OF RAMP".
4. Paint wall adjacent to limiting points a contrasting color and give it extra illumination.

VEHICLE ELEVATORS

Freight elevators were often employed in earlier garages to carry cars between the main floor and the storage floors. They require very little floor space compared to ramps, and eliminate the tractive effort of the automobile in ramp climbing. A single car can be transported several floors by elevator faster than it can be driven up a ramp. Elevators may be used for either customer or attendant parking.

Elevator manufacturers state that freight elevators are no longer made for parking garages, but are being produced for use in sales and service garages. Elevators are generally considered expensive in comparison to ramps, both in first cost and in operation and maintenance. The principal disadvantage to elevators is that they can only provide intermittent service, as compared to the continuous capacity of ramps.

The design requirements of elevators can be readily determined from car dimensions and weights. Some of the older installations observed were limited by the size of the cage, which would not accommodate all cars, but this obsolescence could be avoided by liberal design in new installations. Modern elevator techniques might provide marked improvement over some of the older installations, including automatic doors, automatic leveling, and push button control by the driver without leaving the car seat. With these improvements, the time measured and shown below might be reduced; the basic weakness of intermittent operation cannot be eliminated.

The following tabulation shows the steps required to move a car from the main floor to the third storage level above, based on times observed in several elevator garages. The times shown are somewhat less than the average of those observed because extended delays attributable to the age of the equipment have been eliminated.

<i>Action</i>	<i>Time in Seconds</i>
Drive car onto elevator and stop	10
Close doors and accelerate	6
Travel up 3 floors, 3 seconds per floor	9
Decelerate and open doors	6
Drive car off elevator	7
Close doors and accelerate	6
Travel down 3 floors	9
Decelerate and open doors	6
	<hr/>
Total time for round trip	59

Probably an average round trip time of one minute per car for inbound or outbound operation is the best that can be expected. This time corresponds to a rate of 60 vehicles per hour, and the number of elevators required to handle peak flows may be obtained by dividing the peak flow by 60.

Another limitation to elevator garages is in the operation of the reservoir space. If a lane containing several cars is located opposite each elevator, each individual car must be moved forward one car length each time the front car is loaded on the elevator. Thus, a large number of floor-men are required, or, the effectiveness of the reservoir space is lost.

MECHANICAL GARAGES

A brief review of patents concerning parking garages reveals a number of ingenious methods for mechanically placing cars in stalls. The most common system combines a freight elevator and a power dolly which moves cars horizontally to load and unload them on the elevator. Several large mechanical garages of this type were built during the 1920's, two of which were observed in this study.

Mechanical garages are built as an entire structure, in one case twenty-four stories high. Multiple banks of elevators are employed, each elevator carrying two cars and having access to two or three stalls on each side of the elevator on each floor, or perhaps a total of 200 stalls per elevator. The building must be located with entrance and exit on separate streets, and the elevators

are usually placed in the middle of the block. Incoming cars enter a reservoir space on one side of the elevators, and outgoing cars are delivered on the opposite side. Dolly tracks extend a distance of about two car lengths each side of the elevator on the main floor, and to all parking stalls on the storage floors.

An operator rides on each elevator, which has controls for elevator and dolly movements and a telephone and ticker tape for communication with the cashier's office. A parking operation takes place as follows:

1. Incoming cars are driven in front of the elevators astride the dolly tracks.
2. The elevator is stopped at the main floor and the doors opened.
3. A dolly is run out on each of the two tracks and stopped under the rear axle of the first car in line. A platform is raised up from the dolly, lifting the rear wheels of the car off the floor. (Thus the car may be left in gear, or with the parking brake on.)
4. The dollies are run back into the elevator, carrying the cars with them.
5. The elevator doors are closed and the elevator travels to a floor with vacant stalls. (The door operation is automatic with the starting or stopping of the elevator.)
6. The dollies move the cars into a stall and return to the elevator.
7. The elevator returns to the main floor. The elevator operator removes a part of the identification ticket from each car and places it in a rack, indicating the location of the car.

Whenever cars are to be removed from the stalls furthest from the elevator, the nearer cars in that row, if any, must be reparked. For this reason, one stall is usually left vacant on one side of the elevator in each row. When the garage has a heavy demand, part of the spare stalls are also filled, so that cars to be moved have to be reparked on other floors. The operator must keep account of all such movements by changing the location of the identification ticket in the rack.

Studies made in the mechanical garages observed reveal the fol-

lowing average values for times of the more important steps in operation.

<i>Step</i>	<i>Time in Seconds</i>
Load or unload car	17
Accelerate or decelerate, including closing or opening of doors	5
Travel time per floor	1.2

Computations of the total time required for typical operations, based on the above values, show the following values:

Movement of one or two cars from reservoir space to same storage floor, and return of elevator: eighty-two seconds.

Storage of two cars on different storage floors: 110 seconds.

Delivery of one car, if blocked by another car and space on opposite side of elevator is available: 108 seconds.

Delivery of one car, if blocked by another car and opposite space is not available: 138 seconds.

Delivery of one car if blocked by two other cars and one opposite space is available: 164 seconds.

Storage of one car and delivery of one car from adjacent floor, with no blocking cars: 126 seconds.

Many different combinations of operations can occur, and the rate of delivery must depend on the patronage of the garage (i.e., if patrons leave in the same, or reverse, order of arrival) skill of operator, and speed of equipment. The minimum acceptance or delivery time would appear to be about 1 minute 20 seconds, or at a maximum rate of 45 cars per lane per hour. A two-lane elevator will store cars twice as fast as a single-lane elevator, but cannot deliver them at this rate because customers may all call for cars stored in one tier during a given period. Every delay in loading two cars from different floors, moving blocking cars, and so on, will reduce this rate of delivery.

The advantages of mechanical garages are the storage of a large number of cars in a very small area, and operation with a small number of attendants. The disadvantages are very high costs and an intermittent operation. The reservoir space difficulties are like those in all elevator garages, except that they are intensified by the fact that additional cars must be placed astride

the dolly tracks after each pair is moved onto the elevators. A high rate of turnover is almost impossible in mechanical garages.

SUMMARY

The design and placement of ramp systems are among the most important considerations in laying out a storage garage. There are many different types of ramps, and each has characteristics which suit it for application to certain land parcels, locations, and parking demands. The design of a "new" system is almost impossible, and the choice of ramp for a particular garage can best be made by comparison with other existing garages.

One-way ramps are almost always to be preferred to two-way ramps, except in very small land parcels. Clearway ramp systems are particularly desirable in customer-parking garages, and materially reduce ramp delays in attendant garages, but do not make as intensive use of space as the adjacent-parking types. Curved ramps require more area than straight ramps, but allow easier handling of cars. Thus, from the viewpoint of operation when adequate space is available, a one-way, clearway ramp system with curved alignment is probably the most desirable. Staggered-floor ramp systems have particular advantages on expensive land parcels of odd shapes and small dimensions.

CHAPTER VII

INTERFLOOR DRIVER TRAVEL-MEANS

“Interfloor driver travel-means” is a phrase used to describe various methods of vertical movement between storage and main floors. It includes stairs, passenger elevators, service elevators, and fire-poles.

Acceptance and delivery of a vehicle require a round trip for the *driver* between the reservoir space and the storage floor. Customer-parkers must make two such trips. In attendant-parking, the acceptance and delivery can be combined during part of each day when inbound and outbound movements are approximately equal. An attendant who is to deliver a car to a waiting customer may drive another car to the storage floor and park it as part of the same trip.

During inbound peaks, each attendant must drive a car to the storage floor and then return on foot to the reservoir space for another car. Likewise during outbound peaks, the attendant must travel to the storage floors emptyhanded. Time spent in walking on these trips is from one-half to two-thirds of the *total* handling time, according to time-studies in this investigation (cf. Chapter III). The means of interfloor travel should be selected to require a minimum time and effort consistent with expense and safety.

Interfloor driver travel-means for customer-parking garages must be given special consideration, because of the larger number of persons to be handled and the need for greater safety and convenience. Unlike attendant garages, there are no combined in-and-out vehicle movements. All drivers, therefore, must travel on the means provided. This increases the load during hours when car-movements are heaviest. Many drivers have passengers who also will travel to or from the storage floors.

It can thus be seen that interfloor driver travel-means perform an essential function in garage operation. If they do not have sufficient capacity for peak loads, or fail mechanically, the acceptance and delivery will be slowed to a point of stagnation. This

importance is underlined by the fact that many older garages are currently replacing obsolescent inter-floor travel means with modern equipment.

GENERAL REQUIREMENTS

The first requirement for an interfloor driver travel-means is that it shall have a capacity sufficient to meet peak load conditions. In an attendant-parking garage, this peak load is equal to the number of attendants divided by the average time required to handle one car. For instance, in a garage employing twenty attendants, with an average handling time of four minutes, the interfloor driver travel means must have a capacity of five passengers a minute. In customer-parking garages, the required capacity is equal to the peak rate of demand, plus an allowance for extra passengers. In one customer-parking garage, a count of car occupancy showed 155 passengers in addition to the drivers of 249 cars. The resulting occupancy ratio of 1.6 is about that which has been found in normal urban traffic.¹ It is proper, then, to provide interfloor driver travel means for customer-parking garages with a capacity about two-thirds greater than the estimated peak flow of vehicles.

Speed

The actual speed of operation of interfloor driver travel means is of secondary importance, if adequate capacity is provided. Vertical travel has elements of danger; so speed should not be overemphasized. The time required for driver movements should be kept to a minimum by proper location, and advantage should be taken of such features as self-opening elevator doors.

Location and Convenience

As discussed in Chapter IV, the main floor terminus of the inter-floor driver travel means should be adjacent to the cashier's cage

¹"Use and Capacity of City Streets," Hawley S. Simpson, *Transactions*, American Society of Civil Engineers, 1934, Vol. 99, p. 1012.

and reservoir space. In Chapter V, it was shown that the best location on storage floors for the principal means is the centroid of the parking area. These two requirements are not radically different in most garages, and can be compromised without much difficulty. The location on the main floor is more important, since all drivers must pass that point. Doors or openings on all floors should be oriented so as to lead directly towards drivers' normal walking paths. And those paths should never be unnecessarily circuitous. The importance of proper location is emphasized by the fact that even four feet of extra travel consumes a second—a waste that multiplies with every trip throughout the day.

In providing interfloor driver travel-means the physical effort required in their use should be considered. Customer-parkers cannot be expected to slide down fire-poles, and attendants cannot perform efficiently with repeated trips up and down stairs.

Safety and Auxiliary Travel-Means

The interfloor driver travel-means selected should be free from hazards and should incorporate all recognized safety features. Safety must be given special consideration in customer-parking garages because of the wide variety of patrons and the liability in the event of accidents.

In addition to the principal interfloor driver-travel means, auxiliary means are necessary in case of fire or other emergencies. These secondary means should be dispersed throughout the garage because they often will be useful for attendants who have parked a car on one floor and must unpark another from a stall on a floor above or below.

METHODS OF INTERFLOOR DRIVER-TRAVEL

Stairs are the basic means of vertical pedestrian travel. They may be used quite satisfactorily as the *only* means of interfloor driver-travel in garages that have but one or two floors above or below the main floor. And stairs always are employed as auxiliaries to other methods.

The advantages of stairs are that they may be placed in other-

wise unusable space, are cheap to construct, and have no operating costs. They are continuously available, and have a capacity greater than any demand that can be attained in most garages. In this respect they have the same relationship to passenger elevators as ramps do to freight elevators. No waiting time is involved, and the travel-time depends largely on the agility and ambition of the drivers. In this study, an average travel-time of twelve seconds a floor was measured on stairs in a three-level garage that had no other means of interfloor driver-travel.

The big disadvantage of stairs is the effort required to walk up and down—an effort that increases rapidly as the number of storage levels is increased. Repeated trips throughout the workday are increasingly tiring and time-consuming. Customer-drivers are certain to complain if required to walk more than one or two floors.

Passenger Elevators

In multi-story garages, passenger elevators are the standard means of interfloor travel. Most installations are of the self-service type. Newer installations provide such features as automatic leveling and self-opening doors to simplify the operation and reduce delays. Busy garages need two or more elevators. To ensure use of the full capacity under conditions of peak load, it is sometimes advisable in customer-parking garages to provide an elevator operator to supervise loading and unloading.

Advantages of passenger elevators are primarily in safety and facility. For these reasons, they are the only satisfactory means for customer-parking garages. Disadvantages are the high initial cost, continuing operating and maintenance costs, and the intermittent service that requires drivers to wait for an elevator while it is being used by others.

The operating characteristics of existing garage elevators vary widely and are not representative of the latest design in new installations. For this reason, the time measurements made in this study were not consistent or conclusive, and it was judged better to depend on the design data used by elevator manufacturers.

The actual time of vertical movement of a garage elevator is a small part of the total time required for each trip. For this reason,

and because floor-to-floor distances are small, high-speed elevators are not required. The usual rated speed is 200 feet a minute. The average speed will be something less, because of the acceleration and deceleration required on starting and stopping. Figure 51 shows the distance and time relationship for an elevator travel-

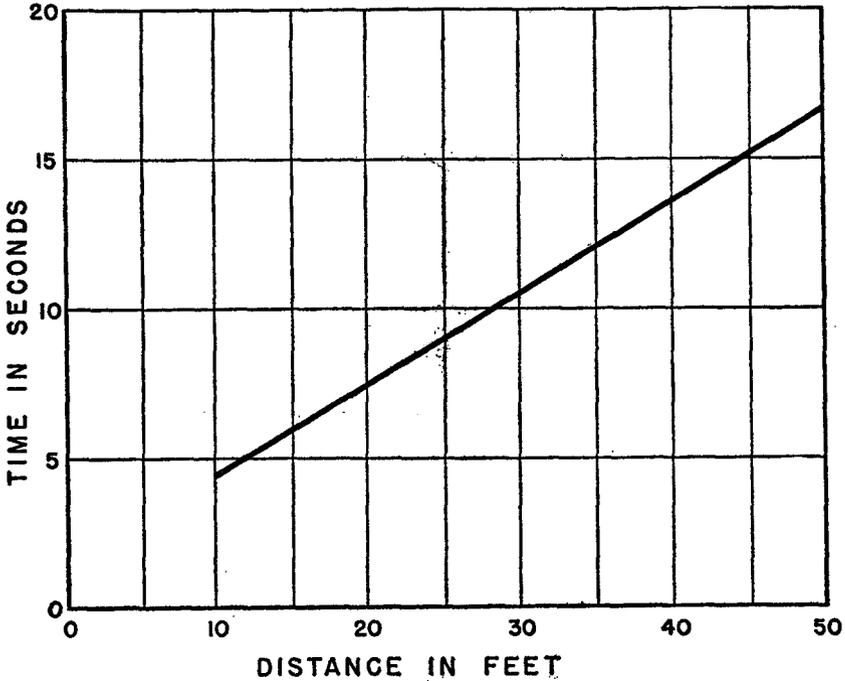


FIGURE 51. Relationship Between Distance Traveled and Elapsed Time for a Passenger Elevator with a Velocity of 200 Feet per Second and Acceleration and Deceleration Rates of 3.5 Feet per Second per Second

ing at 200 feet a minute and with acceleration and deceleration rates of 3.5 feet a second.

Other constants used in the design of fully-automatic self-service elevators are:

Door opening	2.5 seconds
Door closing	2.5 seconds
Passengers getting in	1 second each
Passengers getting out	1.5 seconds each
Reverse direction at top of travel	2.0 seconds
Contingency factor	5%

Design constants for passenger elevators are fairly well standardized, and the number and size of elevators to be installed is based on the expected peak loads and the allowable maximum average waiting-time. The actual number of passengers to be handled affects the time of operation only in the loading and unloading times. But a garage with a large demand will normally have a larger number of floors. This increases the number of possible stops. The maximum average waiting-time is more or less arbitrarily selected to meet the desires of owner and designer. The elevator engineers consulted in this study said one minute was the time usually selected for parking garages. Since whatever period is selected is directly added to the average time of acceptance and delivery in peak periods, probably this figure should be less, say thirty seconds.

In the design of elevators for a particular building and passenger load, computations of total travel time are made for each combination of floor heights, numbers of passengers, and destinations of passengers, with special attention to multiple-destination trips to higher floors. The average waiting-time for another passenger who calls for the elevator when it is in use will be half of this travel time. The number and design of elevators must be such that the average waiting-time for any expected trip will not exceed the selected maximum. If any do exceed this maximum, the need of additional elevators is indicated.

As an example of such computations, let us consider a garage with three storage levels above the street, with a floor-to-floor distance of twelve feet. If a peak flow of 180 cars an hour is anticipated, an elevator capacity of three passengers per minute is required. Starting at the main floor, suppose that three attendants get on, one traveling to the second floor and two to the fourth floor. The time required for the elevator to return for another load may be computed as follows:

Door opening at 1st floor	2.5 seconds
3 Passengers loading	3.0 seconds
Door closing	2.5 seconds
Travel time to 2nd floor	5.2 seconds
Door opening at 2nd floor	2.5 seconds
1 Passenger unloading	1.5 seconds

Door closing	2.5 seconds
Travel time to 4th floor	8.8 seconds
Door opening	2.5 seconds
2 Passengers unloading	3.0 seconds
Door closing	2.5 seconds
Reverse direction	2.0 seconds
Travel time to 1st floor	12.4 seconds
	—
	50.9 seconds
Plus 5%	2.5 seconds
	—
Maximum waiting time	53.4 seconds

$$\text{Average waiting time} = \frac{53.4}{2} = 26.7 \text{ seconds}$$

If the allowable average waiting-time is selected as thirty seconds, one elevator will provide sufficient capacity.

Such computations are the premise of elevator engineers, who should be consulted in determining the design and number of elevators. The garage architect or engineer must be prepared to state the estimated flows of passengers per unit of time (usually by five-minute periods) and the maximum average waiting-time selected.

Service Elevators

Service elevators, or man-lifts, are endless belts mounted in a vertical position with handles and steps attached at proper intervals for carrying passengers up and down. The belt travels at a rate of speed low enough for passengers to step on or off while it is in motion. Installations have been made in several garages, and those observed in this study were successful. A sketch of a typical installation is shown in Figure 52.

The advantages of service elevators are that they have a capacity for continuous movement, require little effort by passengers, and can be placed in a small area. The up-and-down movements are independent and simultaneous.

The chief *disadvantage* is safety, since careless or inept passengers may strike their heads at the floor openings or lose their grip and fall off. They are forbidden by law in some cities and

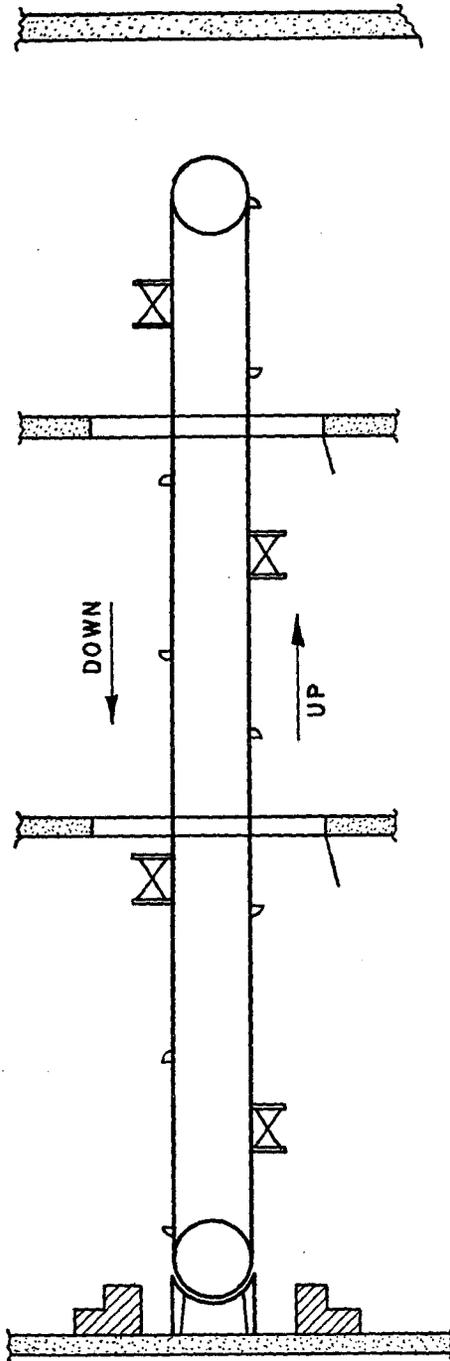


FIGURE 52. Service Elevator, or Man-Lift

states. Initial cost, maintenance, and operating costs are less than for passenger elevators, but still are considerable. Man-lifts are not practicable for customer-parking garages.

The speed of service elevators is seventy-five to ninety feet a minute. As measured in one of the garages observed, this means a travel-time of about seven seconds a floor. The individual steps were on about a twelve-second headway, so that the average waiting time was six seconds.

Numerous safety devices are employed, including magnetic brakes for emergency stops and limit-switches to prevent passengers from being carried over the top pulley. Control cables, parallel to the belt and readily accessible to passengers, are actuated by pulling. The "stop"-movement is in the same direction as the belt travel. Railings are placed around floor openings to prevent the personnel's falling through. Conical shields are placed at the ceiling openings of the "up"-side of the belt to avoid passengers' striking their heads.

Fire Poles

Sliding poles like those used in fire houses have been installed in some attendant-parking garages. They consist of a brass pole four to six inches in diameter, centered in a circular floor opening. A separate pole is provided for each floor, so that a drop of only one story is required. The poles are staggered on each floor, so that an attendant can easily step from one to the other. A thick rubber pad is placed at the foot of each pole.

Such an installation is inexpensive, requires little area, and has a continuous capacity. Disadvantages lie in the one-way operation that requires other means for upward movements, and in limited safety. Not all attendants have the agility required to travel on fire poles. They have no application in customer-parking garages.

The travel time on fire poles, as measured in a large underground garage, was one second for a drop of one floor, and five seconds for a drop of two floors, including the time to shift poles. This is the fastest interfloor driver travel means. In the garage observed, elevators were provided for up-movements, and attendants were not allowed to ride down on them. None of the at-

tendants indicated any dislike of this system. In garages where attendants were allowed to ride down on the elevators, it was observed that the poles were seldom used.

Other Means

Vehicle ramps are sometimes used, especially in parking decks, for interfloor driver-travel. These present some danger to pedestrians, and, in comparison with stairs, waste driver-time and effort. In most staggered floor garages, regular interfloor means are provided on only one set of floor levels, so that drivers from the other section must travel a half-story on the vehicle ramps.

Escalators have been suggested for large customer-parking garages because of their continuous capacity and generally good public acceptance. No such installations are known to exist, probably because of the high cost involved.

SUMMARY

Stairs are the basic means of interfloor driver-travel, and must always be provided as auxiliaries to other means. For garages with only one or two stories above or below the main floor, they are the best and fastest means.

Service elevators or man-lifts are quite satisfactory for attendant-parking garages, providing fast and economical movement. They are forbidden by some building codes because of safety considerations.

Passenger elevators are the standard means of interfloor travel in multi-floor garages, and are highly satisfactory means for transporting customer-parkers. The service provided is intermittent, and the number and design must be such as to keep the average waiting time to a minimum, preferably not over thirty seconds.

CHAPTER VIII

MISCELLANEOUS FEATURES

A room should be provided near the cashier's office for customers waiting for delivery of their cars or who are to meet other people at the garage. This room need not be elaborate, but it should be kept clean and should have comfortable chairs. It should be located directly adjacent to the out-bound reservoir space with large windows with a clear view of the reservoir so that customers can see their cars when delivered. Chairs should be placed facing these windows and the entire layout of the waiting room should be such as to prevent customers from becoming so contented that they converse or otherwise require an attendant to search through a waiting group to find a driver, often blocking the exit for minutes.

Rest Rooms and Check Rooms

Public rest rooms should be provided. They must be kept clean. They usually are placed one floor above or below the main floor to conserve space.

Most garages find it necessary to deny all responsibility for small articles left in cars because of fraudulent claims. It is desirable to have a check room near the cashier's cage. For small garages the cashier may be in charge of the check room, for larger ones an employee can spend part time at the check room and part time at other duties, such as cleaning the rest rooms, etc. In several garages observed, the checking facilities were unused, perhaps indicating small demand for such service. On the other hand, some garages connected with department stores offer a service whereby goods bought in the store may be delivered direct to the customer's car in the garage. This must be considered a function of the store, not part of the garage operation.

Manager's Office; Employees' Dressing Room

The garage manager must be provided with a small office for handling his bookkeeping and for receiving customers' com-

plaints. For the latter purpose it is desirable to have this office comfortable but not elaborate. The manager's office need not be located on the main floor, although this may be desirable in order for him to better supervise the garage employees. Depending upon the size of the garage and the extent of accounting system, additional employees for keeping accounts may be stationed in, or adjacent to, the manager's office.

An area should be set aside for the employees to change from street clothes to uniforms. It should include lockers, rest room, and space for lunching or resting. A suitable location may often be found in an otherwise dead-storage area, if not, this room should be placed on the farthest storage floor.

Service Facilities

To provide a profit margin for garage operation, it is highly desirable to install facilities for greasing, washing, and repairing customers' cars. In fact, many garages rely on profits from such services entirely, since storage fees are insufficient. Such facilities should be located so as not to interfere with storage and delivery. One particularly bad feature observed in several garages was the location of gasoline pumps adjacent to the in-bound reservoir space. For each car filled with gasoline, one lane of the reservoir is blocked. In some garages repair and service facilities are located on the farthest storage floor to interfere least with storage space. In other garages, these operations take place on the ground floor because of the increased ceiling height available for raising cars on lifts and better ventilation.

The sale of gasoline, oil, and accessories and the use of the service facilities will depend largely upon the sales ability of the floor manager. The author observed that many such sales, especially washing, were made without regard to the needs of the customer, who ordered the services on impulse. Reliable service facilities will attract repeat-customers and build general good will.

Fire Protection and Drainage

In a modern concrete and steel garage it may seem hardly necessary to provide an extensive fire protection system. However, the

building codes of many cities require a complete sprinkler system and dividing fire walls. Such requirements, of course, must be met. The most necessary and valuable means of fire protection are small chemical extinguishers placed at convenient points throughout the building.

All floors of a garage should be made waterproof with particular attention being given to the roof, if that is used for parking. In wet or snowy weather, considerable water and snow are brought into the garage on the in-coming cars. This water is distributed throughout the garage and in some cases may create a considerable problem. The effects of poor drainage are (1) the gradual seepage of water through the floor with resultant corrosion on cars parked below, and (2) the accumulation of pools of water. The best drainage system is a shallow trough at the rear of each parking stall with the floor sloping away from the center of the aisle. Vertical drain pipes should be located behind columns or otherwise protected to avoid encroachment on parking stalls and damage to the pipes by moving cars.

Ventilation and Heating

Open-deck garages do not require ventilation facilities. The most extensive ventilation observed for under-ground garages was no more than sufficient, as attendants making repeated trips sometimes complained of headaches and other symptoms of minor carbon-monoxide poisoning. All ventilating ducts should be placed away from damage by moving cars.

It is impossible to heat open deck garages and, in practice, most inclosed garages were found not heated to high temperatures. Although there is a significant movement of customer-demand from open lots and garages to heated garages in cold weather, it is not economically feasible to inclose and heat a garage to meet this demand. It is, of course, necessary to heat the cashier's office, waiting room, manager's office, and rest rooms.

Communication Systems

Often it is necessary to communicate between main and storage floors, as in checking a "lost" car. Standard means of communica-

tion—telephone, telautograph, and pneumatic tubes—are used. The most satisfactory method is an inter-office communication system, with loudspeakers on each floor.

Architecture

Most earlier garages were thought of as business buildings and were constructed with solid walls, well-lighted, heated, and ventilated interiors, and with exterior architecture pleasing to the eye. The poor financial showing of this type of building has indicated that expensive equipment and unnecessary architectural treatment must be avoided. Before the war, it was estimated that the cost of an open-type garage was about one-fourth to one-third that of an enclosed type.¹ With current high construction costs, this advantage becomes more compelling.

Various ways to dress up earlier open-wall construction garages do not add materially to the cost, but result in architecture more pleasing to the eye and more suitable to the surrounding area. Such architectural treatment can be added after the garage has been in operation for some time. This was done in the garage shown in Figure 53. One of the important savings in the open-type garage is elimination of heating or ventilating equipment. Subsequent architectural beautification should not be allowed to enclose the garage to the point where forced ventilation is necessary.

A sound basis of design, one that presents a pleasing appearance, is the cantilevering of the end-bays of the storage floor. This type of construction is shown in Figure 54.

¹ American Automobile Association, *op. cit.*, p. 118.

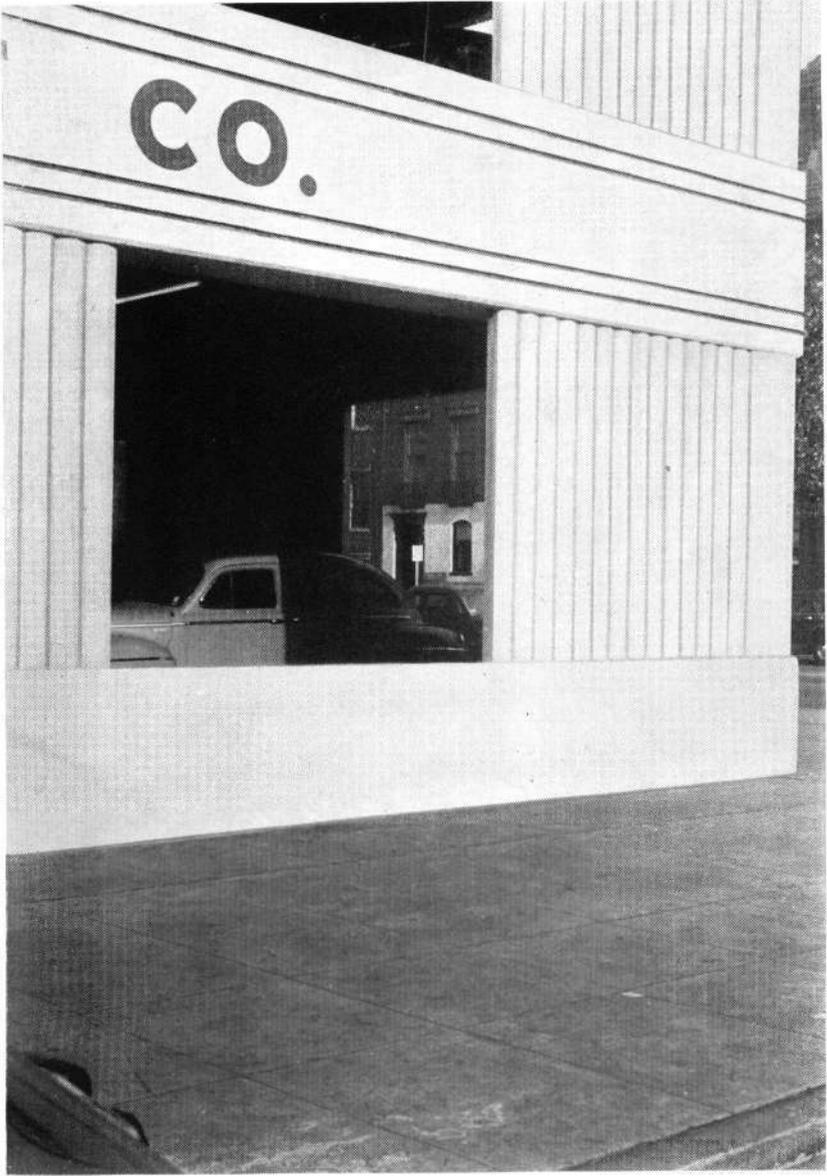


FIGURE 53. Detail of Concrete "Curtains"



FIGURE 54. Open Deck Garage with Cantilevered Floors

CHAPTER IX

TECHNIQUES OF OPERATION

The success of a parking garage depends as much on the techniques of operation as on the physical design. There were several examples in the garages visited where obsolescent or defective design had been, to a large extent, overcome by good management. On the other hand, instances are known where garages with good physical design have experienced unprofitable stages of poor management. This report is primarily concerned with the design, hence, only aspects of operation closely allied with design are covered in this chapter.

Time is the common denominator of all steps in the operation of garages. Some of the longest delays measured in this study were due to faulty operating techniques rather than physical design.

Procedures for Handling Cars

For handling cars, detailed procedure must be established that is based on experience in other parking facilities, on the physical design of the garage, and on the types of patrons. This operating procedure will vary among garages. It must be adapted to current conditions.

Cars should be removed from reservoir space to storage floors in an orderly manner so that attendants can move to the next car to be stored without confusion. It is customary to empty the reservoir space one lane at a time, in rotation. This allows a maximum use of the reservoir and gives customers time to unload.

General rules on right-of-way within the garage will help prevent accidents and will speed up the handling of cars. An example of such a rule is the one that cars traveling down the ramp have the right of way over those traveling up or entering the ramp.

Order of Filling Stalls

At any particular time, the parking activity should be spread throughout the garage so as to reduce interference between cars.

Cars known to be stored for long periods or all day should be in rear rows of double parking or in the stalls adjacent to the ramps. This leaves the most accessible stalls for short-term, high turn-over parking. The placement of cars may be left to the judgment of attendants or controlled by the floor man through pre-marked tickets.

The use of stairs or fire poles for down-travel must generally be mandatory in order to leave other means available for movement to upper floors. Such rules may apply only at peak hours.

Emergency Procedure and Lost Cars

Standard procedure must be established for handling such emergencies as fire, accidents, or mechanical failure of vehicles. Whenever cars fail to start or have flat tires, it is often advisable to leave them parked until the rush period is over. The owner may be invited to make his own repairs or to wait, but an extended delay which will affect many other customers cannot be tolerated.

In spite of good location systems, cars will sometimes be lost and cannot be identified without searching through all the cars stored. In one instance, an employee searched twenty minutes before discovering that the wrong make of car was shown on the location stub. One way to reduce these delays is to ask the owner of the lost car to accompany the attendant to the storage floor.

Undelivered Cars

Often when a car is delivered to the outbound reservoir, the customer will not be there to claim it. To avoid blocking the exit, it is a good plan to provide space in the reservoir where cars can remain out of the way until claimed.

NUMBER OF ATTENDANTS

The number of attendants in a garage is the variable under the most direct operational control. After a garage has been opened for a short period, the times of acceptance and delivery and the pattern of parking demand can be assessed and the number of

attendants adjusted accordingly. Data were collected during an outbound peak period in an attendant-parking garage to analyze the rate of customer-demand and the delivery time of the attendants. The arrival of customers was determined by recording the number waiting for cars at five-minute intervals. The delivery-time of cars was found by timing each attendant as he picked up the location stub for the next car. The number of attendants passing the cashier's office during the five-minute period is equal to the delivery of cars during that time. These data are shown in Figure 55, where the horizontal distance between the arrival and delivery curves is equal to the average waiting time of customers, and the vertical distance between the curves is equal to the number of customers waiting at any particular moment. The number of customers waiting exceeded seventy drivers in some cases, plus passengers; the average waiting time was nearly thirty minutes.

The rate of delivery is seen to have two slopes, one preceding 9:15 P.M. when some cars were still arriving to be parked, and afterwards when the operation was entirely outbound. The slope of the latter part of the curve is equal to four minutes per attendant per car. During this time there were eight attendants on duty. A more detailed analysis of the delivery time is shown in Table XI in which long delays for lost vehicles or for other reasons have been eliminated.

Table XI

AVERAGE TIME FOR DELIVERY OF CARS BY DIFFERENT ATTENDANTS

<i>Attendant</i>	<i>No. of Cars Handled</i>	<i>Average Time Per Car Handled</i>
A	13	2 min. 52 secs.
B	26	3 min. 2 secs.
C	26	3 min. 3 secs.
D	13	3 min. 12 secs.
E	21	3 min. 14 secs.
F	24	3 min. 21 secs.
G	22	3 min. 40 secs.
H	16	4 min. 32 secs.

Average time for all attendants 3 minutes 21 seconds.

Long waiting-times imposed on customers during the peak period in this garage should be avoided whenever possible. Minor

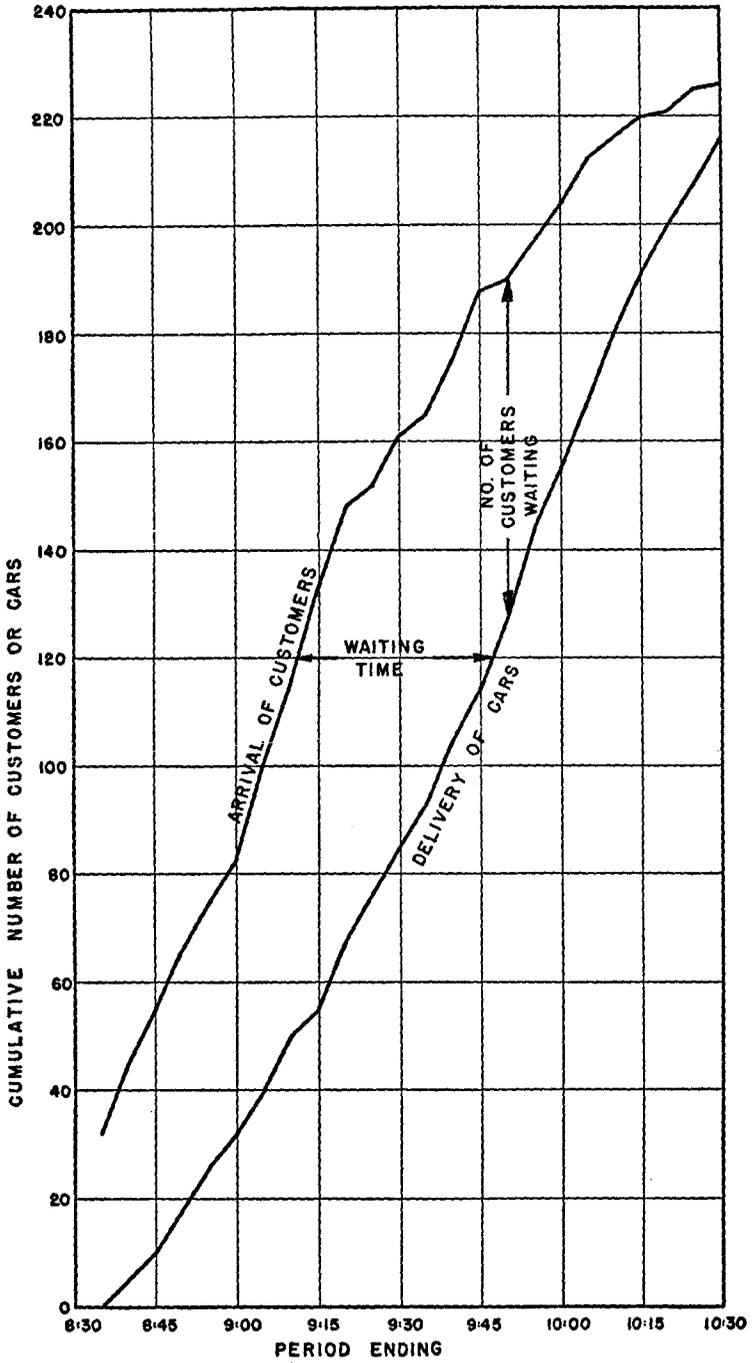


FIGURE 55. Time Relationship Between Driver Arrival and Car Delivery During Evening Shopping Peak

bottlenecks exist in the operation of passenger elevators and in the long distances attendants must walk on the storage floors. However, the garage is of good design and of reasonably fast operation, as shown by the fact that the actual time of handling cars averaged three minutes, twenty-one seconds. The only way that customer waiting-time could be materially reduced is by additional attendants.

If two more attendants had been employed (for a total of ten) and the same gross rate of delivery of four minutes per attendant per car had been maintained, 100 cars would have been delivered every forty minutes. Thus, the rate of delivery would approximately equal the rate of arrival, and the large pool of waiting

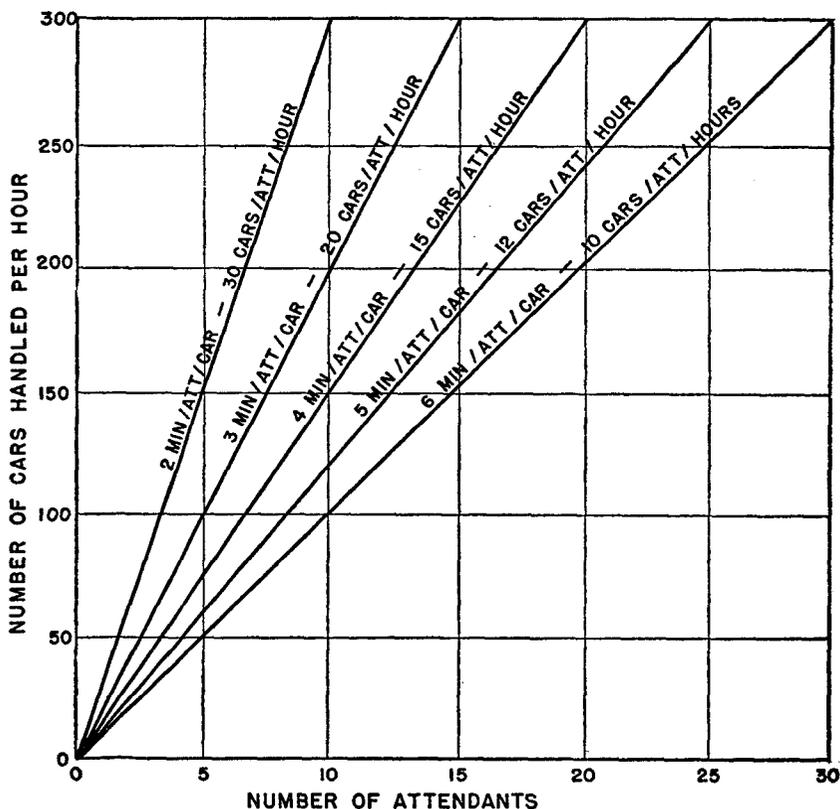


FIGURE 56. Relationship Between Number of Attendants, Rate of Handling Cars and Total Number of Cars Handled

customers would not have accumulated. The average waiting time might have been reduced to ten minutes or less.

Rate of Delivery

Even though customers arrive and call for their cars at random (See Chapter III), cars will in general be delivered by attendants on a more nearly uniform basis, particularly when a group of customers is waiting. This average time of delivery is fairly constant throughout any peak period. In different garages it may vary from two to six minutes. Figure 56 shows the relationship between this rate or the number of cars handled per attendant per hour, the number of attendants and the total number of cars handled. For instance, it will be seen that twenty attendants handling cars at a rate of one car every five minutes per attendant will handle 240 cars an hour. The experience of most garage operators, borne out by the performance rates shown in Chapter III, is that attendants will not average more than fifteen cars an hour.

Peak rates of inbound and outbound movement represent the most intense desires of motorists to park or un-park their cars. It is during these times that they form their judgments of a garage, particularly if long delays are experienced. To satisfy the public at these periods, garages should be prepared to deliver cars at as high a rate as is economically practicable. This rate should equal the rate of customer-arrivals for the average peak hour. During off-peak periods, the excess of attendants available may be given other duties. Working schedules may be staggered to have two shifts of attendants at the evening peak.

IDENTIFICATION TICKETS¹

Identification tickets, or parking checks, are highly important in garage operation. With an orderly system for locating stalls, tickets can be used to speed car handling and make maximum use of available space.

¹In the preparation of this section, frequent reference has been made to "An Analysis of Identification Tickets for Off-Street Parking Facilities," a thesis by Stanley T. Siegel, Bureau of Highway Traffic, Yale University, 1947.

The principal functions of identification tickets are:

1. As a receipt to the customer, indicating the acceptance of his car for storage, and identifying him as the rightful owner when he returns for it.
2. As a means of identifying and locating the car.
3. As a bookkeeping device, on which the duration of storage and parking charges are noted and for accounting control of employees.

Ticket size, color, and content vary. The number of sections may be from one to five:

(1) *Customer's Claim Check*. The part given the customer has several purposes. It identifies the parking facility to the customer and the customer with his car. It offers an advertising medium and allows a public statement of the parking fees and the conditions of parking. The size should be large enough to hold all this information and not be easily misplaced, yet small enough to fit in ordinary pockets.

The usual contents are:

a. Name and address of parking facility. Necessary for new or out-of-town parkers, and has a certain advertising value.

b. Identification number. A serial number common to all parts of the ticket.

c. Fee schedule. Sometimes required by ordinance, it avoids misunderstandings. •

d. Conditions of storage. A quasi-legal statement of extent of liability, and particular information on movement of cars between different facilities. A statement may be included as to the hours of operation.

e. Time in. Time-stamped when the ticket is issued as a reference for the customer and to avoid misunderstandings. The time out is not usually stamped on this section.

f. Space for validations. Necessary only when garage has arrangement with nearby merchants whereby the customer's cost is reduced in return for shopping or other patronage.

g. Advertising. Either for the garage or for nearby merchants. In some cases, advertising of the latter type pays the entire cost of the tickets.

(2) *Car Stub*: The car stub identifies a particular vehicle. It needs only to contain the serial number of the ticket, printed large and legibly enough to be read at a distance of about fifteen feet. It is usually placed under the windshield wiper, but may be tied on the door handle or elsewhere. It should be located so that an attendant can easily read it from the aisle.

(3) *Office Stub*: The office stub is primarily a bookkeeping device. It is used to keep a record of the duration of parking, the amount of money collected, and the location of the car. The usual contents are:

a. Identification number.

b. Time In and Time Out. When the floor-man issues a ticket for a car, he time-stamps the office stub. The time stamp usually indicates the date, hour, minute, and A.M. or P.M. As the customer presents the check for his car, the cashier selects the corresponding office stub and time-stamps it for the time out.

c. Enumeration of charges. The parking fee is usually stamped on the office stub by cash register. In garages offering washing or other services, the desired service is marked down on the office stub, and a corresponding charge is made when performed. More extensive services or repairs require more complete invoices, which may or may not be printed on the ticket.

d. Location or identification of car. The extent of this item depends on the location system used in the garage. It is filled out by the floor-man or attendant, as described below.

(4) *Location Stub*: The location stub is used by the attendant to locate and identify the car for delivery. It is attached to the office stub until the customer calls for his car. It is then detached and placed in a rack to signify that the car is wanted. It contains the identification number and location information.

(5) *Release Stub*: The release stub is connected to the office stub and contains only the identification number. It is given to the customer after he has paid for his parking, as a temporary receipt to identify him with his car when it is delivered. In case a car is not delivered promptly, it also allows the customer to ask for a recheck. The release stub is collected at the exit, to insure against theft of cars.

Number of Parts

The number and content of different parts of identification tickets depend on the size of the parking facility, the amount of service offered, and the extent of bookkeeping. All five parts may be used as described. In this event, each part serves one purpose; and all except the office stub may be discarded when the car is delivered. When fewer parts are used, the contents are not as uniform.

Four-part tickets usually eliminate the release stub or the location stub, substituting the office stub for either purpose, the claim check being used for accounting purposes.

The elimination of the release stub and use of the office stub or claim check as a location stub requires only three sections. This system is quite satisfactory for small facilities which do not offer service. Customer-parking garages may use a three-part ticket consisting of claim check, office stub, and release stub.

Two-part tickets are commonly used in lots and consist simply of a claim check and car stub. Accounting is accomplished by keeping a record of the serial numbers of tickets issued and the collection of claim checks. The lack of an office stub allows dishonesty on the part of employees, who may reissue some tickets and pocket the second fee collected.

Some lots issue only one-part tickets—a customer's claim check—which obviously does not satisfy the functions of location or accounting.

Special Tickets

Some of the special identification tickets employed are:

Medallions, windshield stickers, or ticket issued to monthly customers to reduce bookkeeping and repeated issuance of tickets.

Service and repair tickets of special color or larger size to attract attention of attendants and for recording of charges.

Hotel tickets, sometimes with an extra section for the use of the hotel.

The purpose of a location system is to assist attendants to find and identify a car when it is to be un-parked and delivered. It consists of a regular method of identifying each stall or group of

stalls and placing information on the location stub that will identify the car or the stall in which it is parked. Such procedure is unnecessary in customer-parking garages.

The principal types of location systems are: (1) individual stall marking, (2) area marking, and (3) no marking.

In the individual stall-marking system, each stall is identified by a combination of letters and numbers indicating the floor and the specific location on that floor. A regular and easily-remembered system is necessary, such as lettering each aisle or row of cars, and numbering the stalls in each row consecutively from one end of the building to the other. Each floor is laid out in a similar manner, so that stalls having the same numbers on each floor will have the same location relative to the interfloor driver travel-means and ramps. Identifying numbers for each stall are painted on the floor, on the beams directly overhead, or on adjacent columns. This number is marked on the identification ticket for the car which is parked in that stall. The identification number on the car stub and the location ticket provide an additional check, in the event that cars are moved or a mistake is made. If necessary, the car registration or make can be written on the location stub as an extra means of identification. The system of individual stall-marking is the most accurate of any and provides for the rapid and positive location of cars. It is difficult to apply in garages where cars are regularly parked in the aisles, or in double rows, because often cars are moved to several different locations, and the ticket information cannot be kept accurate.

In the area-marking system, storage floors are subdivided into areas, such as the bays between columns, holding from three to ten cars. Each area is designated by a number, or combination of letters and numbers in an orderly fashion, as described for individual stall markings. Cars within the separate areas are identified by car stub, registration number, or make. This system works well when cars are parked in double rows, allowing cars to be moved within an area without losing identification.

The no-marking system depends upon identification of individual cars by car stub, registration, or make without regard to their location. Attendants must search through cars until the desired one is found. As each attendant must search individually,

time is always wasted, and there is no carry-over of information, except when the attendant may, by chance, have parked the same vehicle for which he is searching. This system is usually found in small lots where all available space, including aisles, is used and where "stalls" do not exist. It is entirely unsatisfactory in a large or busy facility and requires too much searching time for attendants. In garages and lots employing this system, delays of one to five minutes frequently occurred while an attendant searched for a car. The system has been further weakened by the practice of issuing one registration plate. This requires cars to be *driven into* stalls to leave the plate visible.

Issuance of Tickets

Identification tickets are issued by the floor-man as each car enters the garage. In attendant-parking garages, tickets are issued in the reservoir; in customer-parking garages, they can be issued on the main or storage floors.

The floor-man time-stamps each ticket immediately before issuing it to a customer. The time-clock may be set to show date and time of day. Some garages use the Army-Navy, or twenty-four-hour, clock system, which simplifies the calculation of elapsed time. Some show time to the nearest minute, others tenths of hours. A good practice sets the cashier's time clock from five to fifteen minutes late relative to the floor-man's clock, which is kept on standard time. Thus, a customer might receive a check stamped with a time-in of 3 P.M., and returning a full hour later, have the time-out stamped as 3:50 P.M. This has good public relations value, and avoids any arguments with customers over the exact duration of parking.

The usual practice is for the floor-man to attach to the car all of the ticket except the customer's claim check. An attendant then drives the car to a storage floor, finds a vacant stall, and parks it. He then writes down the stall number on the office stub (including location and release stubs), detaches these from the car stub, and returns them to the office. The entire responsibility of car placement is thus placed on attendants, and a continuous check on the number of empty stalls cannot be had.

A better system places stall or area numbers on tickets before they are issued, marking tickets only for vacant stalls. Then the floor-man can immediately detach the office stub and file it with the cashier, while the attendant can drive directly to the proper location, sure of finding a vacant stall. As each car is un-parked, another ticket is marked with that stall number, and issued for another car. The manager knows exactly how many stalls are available, and may keep the garage more nearly full.

When information is needed as to the make and model of car or the registration number, the floor-man must note this information on the ticket as he issues it. The registration number is harder to use, but more accurate than the make of car, since the floor-man may often misjudge the latter.

Summary

The inter-relationship of garage design and operation is demonstrated by the choice of ticketing and car handling procedures and the determination of the number of attendants required.

A standard procedure for handling cars is necessary for efficient operation. It should cover such items as the sequence of storing and delivering cars, right of way rules, and methods of meeting minor emergencies, such as unlocated cars and flat tires.

The number of attendants employed varies with the parking demand and the unit-time of handling cars. The principal reason for long waiting-periods when customers call for their cars is a shortage of attendants.

Identification tickets are among the essentials of garage operation. They provide a receipt for the customer, a means of locating cars, and of accounting-control.

CONCLUSIONS

Many garages built during the financial and automotive boom of the 'twenties are not filled to capacity, even when located in the central business districts of cities with large excess demand for parking space. Some garages have failed financially; some have been converted to other uses. Yet everywhere is recognition that more off-street parking *must* be provided if the decentralization of cities is to be controlled or the potentialities of free-wheel transportation realized.

The study described in this report was undertaken to evaluate the physical design-features of parking garages from a traffic engineering approach. Existing garages and lots were used as laboratories, and time-motion studies as tools for comparing the various features. Valuable information was obtained, not only on design but on fundamental aspects of garage operation. The author believes that off-street parking garages, properly located, designed, and operated, will provide effective and permanent solutions to the Number One problem in cities today—"Where can I park my car?"

Steps outlined hereafter are logical and fundamental in the creation of parking facilities. Detailed procedures for some of the major steps are beyond the scope of this report. Points of interest to traffic engineers are emphasized, without discounting other important aspects, including structural design and financing.

Assessing the Parking Demand

The first step in planning a new garage should be to analyze the existing and potential parking demand. Answers must be sought to questions such as the following:

What type of parkers—shoppers, businessmen, theatre-goers, hotel guests, white-collar workers—may be expected to use the garage?

How many parkers of each type?

What are their time-characteristics—when do they come, how long do they stay, what are weekly and seasonal variations in demand?

How much are they willing to pay for parking?

Where are the major destinations of each type?

Answers to these, and other questions concerning the characteristics of parking demand, will vary for each city, and for each specific area in a city in which a garage may be built. There is no easy, precise way to make such evaluations, but an approach may be made through municipal parking surveys, such as have been conducted recently in many cities. Much can be learned from the demand characteristics of garages similar in location and design, garages that serve a similar group of parkers. The demand characteristics shown in Chapter III are typical and form a basis for initial comparisons.

Locating the Garage

One of the major results to be gained from evaluating parking demand is the determination of *desirable* locations for garages. Contours of parking-demand may be drawn, and various land parcels rated as to their relative value as potential parking facilities.

At the same time, a survey should be made of available garage sites. Many parcels will be unavailable because of high land-values and existing buildings; others are precluded by cultural conditions such as inviolable monuments, parks, and historic shrines. Some parcels otherwise available may be impractical because of odd shapes or restricted dimensions.

Advantageous features of garage sites are these:

A rectangular site

Minimum dimensions 120 x 120 feet

Location on or near major arterial streets

Location on side of central business district towards the origin of most potential parkers

Location allowing main flows of vehicles to arrive and depart by making right-hand turns into and out of the garage

Access on two or more streets

Location on a sloping land parcel, which will allow use of multiple entrances and exits to different levels, without ramps.

A compromise must usually be made between desirability and availability. Experience shows that an improperly located garage, even if only a few blocks away from the centers of parking demand may be a failure, both financially and as a means of solving the parking problem.

Capacity to be Provided

Another important value from analysis of parking demand is the capacity of storage facilities warranted at any particular site.

There is an unfortunate tendency to speak in terms of large numbers in regard to garage capacities. Such figures may often become catch words and do not reflect actual requirements, as in the often used phrase "thousand-car garage". To avoid concentration of large numbers of vehicles and to fulfill the parking demand, it will often be desirable to construct several garages of limited size rather than one or two of great capacity. In most downtown areas the practical capacity of garages is limited by the adjacent street system. A study should be made of existing street-traffic flows and their inter-relationship with garage traffic, as represented by left turns, one-way streets and so on.

The extent and quality of adjacent facilities must be reviewed, because a new and superior facility may attract business from these, thus being subject to greater demands than might be forecast. Some of the busiest and most profitable garages observed in this study had capacities of 150 to 300 cars. The rate of turnover is often more important than gross capacity; e.g., one garage with 150 capacity averaged 400 cars a day, with a record peak of 1000 cars in one day.

Corollary to the question of capacity is the choice between a parking lot or a garage at a given site; and if a garage, what the relationship of height to area should be. Many small land parcels do not warrant the construction of garages because ramps will take up too much of the available area. For instance, a circular

ramp occupies an area about ninety feet in diameter. If a ramp of this type is placed on a lot 100 feet by 200 feet, there is no increase in storage capacity for two-level parking. A third level will provide 50 percent more capacity than a simple parking lot, but the revenue must pay the cost of the entire building.

A generally accepted rule is that garages should not be built with more than four or five storage levels above ground. The basis for this rule is the experience of garages with more levels that have found operation of the top floors uneconomical. Similarly, a garage with an excessively large floor area may require excessive time and effort for handling cars. The determination of relative height and area should be made through a study of drivers' travel-time.

Customer—vs. Attendant-Parking

A selection of customer- or attendant-parking should be made early in the design of the garage because different design standards apply to each type. The choice should be based on the parking demand and on relative costs.

The element of parking demand that most directly affects this choice is the extent and occurrence of peak flows. In a garage with uniform rates of flow throughout the day, attendants may be kept busy and enough may be hired to maintain handling rates that will not require long waits by customers. On the other hand, if inbound and outbound movements occur in sharply accentuated peaks, a large number of attendants will be required at these times and not in off-hours. Some peak movements are so intense that it is not practicable to handle them by attendants without requiring long waits by patrons.

More cars can be stored in a given area by attendants than by customers because they require less space for maneuvering, and double-row parking can be used. On the other hand, payroll costs are higher in attendant-parking garages. Local labor and construction costs must be evaluated in determining the economic choice between the two types.

There is a general belief that most motorists do not wish to park their own cars in garages because of the difficulties in driving

on ramps and parking in restricted areas. This is not necessarily true, as several large garages are now operating successfully with customer-parking. While many motorists say they do not like customer-parking garages, it may be found that most of them have never parked in such a garage, and hence do not have a fair basis of comparison. A desirable feature to many motorists is that they can handle their own car, and can lock it in storage.

General Layout

Many of the major features are affected by local considerations of topography, street systems, and the shape of land parcels. Among such items are the location of entrances, exits, and ramp systems. The inclusion of service facilities or stores as part of the same building should be determined in advance, and their approximate placement determined.

Perhaps the most important step in general layout is the selection of the ramp system. No one system is best, and several alternatives should be tried to determine which best suits the land parcel dimensions and the vehicle flows expected. In a two-level parking deck, there will be fewer movements on the ramp, and a simple type may be satisfactory. More adequate ramp systems have a large capacity for the flow of vehicles and should be combined with enough storage capacity to use their capacity. In large garages, the number of stalls to be gained through the use of adjacent-parking type ramps is of less significance than is the freedom for the movement of vehicles.

Consideration should be given to providing storage levels both above and below ground, to keep travel-times on ramps and inter-flow driver-travel means at a minimum.

Design Standards

Throughout earlier chapters, certain recommendations have been made for the character and dimensions of design features, as they affect the movements of cars and drivers. These are summarized below:

Entrances and Exits:

Number—single entrances and exits, with multiple lanes, are preferable to several openings.

Location—as far from street intersections as possible, and oriented to favor right turns.

Width of lanes—12 feet

Inbound Reservoir Space

Capacity—based on expected average peak flow, as shown in Figure 18

Lane width—12 feet

Number of lanes—4

Outbound Reservoir Space

Number of lanes—at least 2

Parking Stalls

Type—back-in stalls at right angles to access aisles

Length—18 feet

Width—8 feet for attendant-parking
8 feet 6 inches for customer-parking

Access Aisles

Width—22 feet for stalls at right angles

Construction of Parking Floors

Clear span construction, equal to Unit Parking Depth, (58 feet) recommended

Column spacing, when clear span is not practicable, 27 feet 6 inches between column faces

Clear ceiling height 7 feet 6 inches

Ramps

Slope—maximum 15 percent

Width between curbs

Straight ramps—minimum 9 feet

Curved ramps, inside lane—minimum 12 feet
Curved ramps, outside lane—minimum 10 feet 6 inches
Curvature—minimum radius measured at face of outer curve of
inside lane, 30 feet

Curbs

Height—maximum 6 inches
Width, side curbs, minimum 12 inches
Width, center island
 Straight sections minimum 12 inches
 Curved sections minimum 18 inches
Superelevation of Curved Ramps 0.1 to 0.15 foot per foot

APPENDIX I

Relationship Between Critical Dimensions of Cars and Widths of Access Aisles

A certain aisle width is required to move a car into or out of a parking stall and to turn it for driving along the aisle. The aisle-width required for this movement is less for flatter parking angles. It also varies inversely with the width of stall and the clearance allowed between moving cars.

The critical dimensions for such movements are shown in Figure 25. To simplify the problem it is necessary to make certain assumptions, viz:

1. The minimum turning radius of right and left turns, and backward and forward movements are the same. (For computations, the largest radius for these movements should be used).
2. The movements into and out of a stall are identical. (The movement out of the stall will be considered in deriving the formulae).
3. The car is driven along a straight path until the clearance point is reached, and the wheels are turned the maximum amount for the turning portion of the movement.
4. Slippage of tires on the pavement is negligible.

DRIVE-IN STALLS

The movement to be considered will be the backing out of a car parked on the right side of an aisle, as shown in Figures 26 and 27. This movement may be divided into two parts: (1) backing out, with the wheels straight, to the point at which it will clear the rear bumpers of adjacent cars during the turning movement, and (2) the turning movement from this point to the position in the aisle parallel to the curb or wall.

Straight Backing Movement

For the larger angles of parking, the back-out distance is determined by the clearance of the right-rear bumper of the car to the

left. (Point X on Car II, Figure 27). For smaller parking angles, it is determined by the clearance of the left rear bumper of the car to the right (Point Z on Car III, Figure 26).

It is convenient to consider the movement of the rear axle of Car I relative to the adjacent cars and measured along the path of straight movement.

Movement Limited by Car to Left

Relative to Car II, the rear axle of Car I is already off-set towards the aisle by a distance $S \cot \theta$, because of the parking angle. In order for Car I to clear the left rear bumper point X, the rear axle must move a distance equal to the distance from the rear axle of Car II to point X, or $O_r - b_r$; and must further move back until the front bumper clearance point Y will clear point X as the car turns, or a distance $= \sqrt{R^2 - (r + t_r + O_s + i - c)^2}$

The algebraic sum of these distances is

$$O_r - b_r + \sqrt{R^2 - (r + t_r + O_s + i - c)^2} - S \cot \theta$$

Measured perpendicular to the aisle, the distance moved is

$$\sin \theta [O_r - b_r + \sqrt{R^2 - (r + t_r + O_s + i - c)^2} - S \cot \theta]$$

Movement Limited by Car to Right

Relative to Car III, the rear axle of Car I must move a distance $s \cot \theta$ to come abreast, because of the parking angle. To clear point Z, it must move back the distance from the rear axle to point Z, or $O_r - b_r$, less the distance

$$\sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}$$

The algebraic sum of the distance is

$$O_r - b_r - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} + S \cot \theta$$

Measured perpendicular to the aisle, the distance moved is

$$\sin \theta [O_r - b_r - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} + S \cot \theta]$$

Critical Parking Angle

The angle at which the limiting point changes from the car on the left to the car on the right, or vice versa, can be determined by equating the two backout distances.

$$O_r - b_r + \sqrt{R^2 - (r + t_r + O_s + i - c)^2} - S \cot \theta =$$

$$O_r - b_r - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} + S \cot \theta$$

Canceling like terms and solving for θ' this equation becomes

$$\theta' = \cot^{-1} \frac{\sqrt{R^2 - (r + t_r + O_s + i - c)^2} + \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}}{2s}$$

This equation will determine the critical angle of parking for clearance to the right or left, when solved for a given design-vehicle, stall width, and clearance.

Turning Movement

The stall width required for the turning movement is not affected by the location of the clearance point to the left or right. It may be measured by considering the location of the turning center. The distance from the turning center to the far side of the aisle is: $R' + c$.

The distance of the turning center from the outermost part of the car (left rear bumper) as it starts to turn, measured perpendicular to the aisle, is

$$\cos \theta (r + t_r + \theta_s) + \sin \theta (O_r)$$

The aisle-width required for the turn is equal to the difference between these distances and is

$$R' + c - [\cos \theta (r + t_r + O_s) + \sin \theta (O_r)]$$

Total Aisle Width for Drive-In Movements

For angles of parking greater than the critical clearance angle, the aisle width required for backing and turning is

$$= \sin \theta [O_r - b_r + \sqrt{R^2 - (r + t_r + O_s + i - c)^2} - S \cot \theta] \\ + R' + c - \cos \theta (r + t_r + O_s) - O_r \sin \theta$$

$$\text{or } R' + c - \sin \theta [b_r - \sqrt{R^2 - (r + t_r + O_s + i - c)^2}] \cos \theta (r + t_r + O_s + S)$$

For angles of parking less than the critical clearance angle, the aisle width is

$$\sin \theta [O_r - b_r - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} + S \cot \theta] \\ + R' + c - \cos \theta (r + t_r + O_s) - O_r \sin \theta$$

$$\text{or } R' + c - \sin \theta [b_r + \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}] - \cos \theta (r + t_r + O_s - S)$$

BACK-IN STALLS

The movement to be considered will be that of driving out a car parked on the right side of an access aisle, as shown in Figure 28. The two separate parts are, again, driving with the wheels straight to the point at which the right rear fender of the moving Car I will clear the left front bumper of the car to the right (Point Q on Car II, Fig. 28) during the turning movement; and the turning movement into a position in the aisle parallel to the curb.

The rear axle of Car I must move a distance equal to $S \cot \theta$ to come abreast of Car II because of the parking angle. To clear the left front bumper point, the rear axle of Car I must move forward a distance equal to the wheelbase and front overhang of Car II, less the distance which the turning clearance will allow point P on the right rear fender to clear point Q, or

$\sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}$, and less the front bumper of Car II.

The algebraic sum of these distances is

$$O_f + B - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} - b_f + S \cot \theta$$

Measured perpendicular to the aisle, the distance moved is $\sin \theta [O_f + B - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} - b_f + S \cot \theta]$

Measured by the location of the turning center, the aisle width required for turning is equal to the maximum turning radius of the front bumper, plus clearance, or $R + c$, minus the distance from the turning center to the outermost part of the car (a right front bumper) as it starts to turn, or

$$\cos \theta (r + t_r + O_s) + \sin \theta (B + O_r)$$

The total aisle width, then, for driving out and turning is

$$\begin{aligned} & R + c - \cos \theta (r + t_r + O_s) - \sin \theta (B + O_r) \\ & + \sin \theta [O_r + B - \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} - b_f + S \cot \theta] \\ = & R + c - \sin \theta [b_f + \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}] - \cos \theta (r + t_r + O_s - S) \end{aligned}$$